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INTERNSHIP REPORT

SUSTAINABLE FINANCE AND CLIMATE CHANGE IN THE CONTEXT OF THE INSURANCE SECTOR OF PORTUGAL

DANIEL COOPER MUNDY

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SUPERVISION:

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ACRONYMS AND ABBREVIATIONS

AAE – Actuarial Association of Europe

ASF – Insurance and Pension Funds Supervisory Authority

CAPM – Capital Asset Pricing Model

CAT – Catastrophe/catastrophic

DNB – De Nederlandsche Bank

EEA – European Economic Area

EIOPA – European Insurance and Occupational Pensions Authority

EurACI – European Actuaries Climate Index

GLM – General Linear Models

IASB – International Accounting Standards Board

IFoA – Institute and Faculty of Actuaries

IFRS – International Financial Reporting Standards

INE – National Statistics Institute of Portugal

LGT – Loss Given Transition

NACE – Nomenclature des Activités Économiques dans la Communauté Européenne

NECPs – National energy and climate plans

NGFS – Network for Greening the Financial System

OECD – Organization for Economic Cooperation and Development

ORSA – Own Risk and Solvency Assessment

RNC2050 – Road Map for Carbon Neutrality 2050

SDG – Sustainable Development Goals

SIC – Standard Industrial Classification

TCFD – Task Force on Climate-related Financial Disclosure

TEG – EU Technical Expert Group

TSC – Technical screening criteria

TVF – Transition Vulnerability Factor

UNFCCC – United Nations Framework Convention on Climate Change

VA – Value added (macroeconomic variable)

ABSTRACT AND KEYWORDS

This study seeks to evaluate climate-related risks under different scenarios, mainly the risks of turning into a sustainable financial system, driven by the Paris agreement, European targets and local strategic agendas. As well as to evaluate the limitation of the historical information to model the materialization of climate changes in Portugal.

Furthermore, this study has the objective to offer a broad overview of literature review on climate-related risks from different perspectives and studies. In fact, this study aims to assess, from a harmonized framework, the materialization of climate-related risks, based on coordinated efforts among governments, supervisors and central banks.

In particular, the nature of climate-related risks embraces assets and liabilities in an insurance company, for this reason, this study introduces benchmarks to monitor the different components of an insurer's value chain and how these benchmarks might interact with the findings of this study.

Overall, this study was developed under a combined perspective, mixing modern financial theory, information availability assessment, macroeconomic experts' opinions, local macroeconomic models, assets valuation methodologies, actuarial science perspective and scenarios with a widely public database.

KEYWORDS: Sustainable finance; Paris agreement; Climate-related risks; Physical risk; Transition risk; Financial stress test; Resilience.

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I CHAPTER 1: INTRODUCTION

During the last years, sustainable finance has been a central theme in the international agenda, as it is essential to align the financial system with existing investment needed to achieve carbon neutrality in the economy during the XXI. In 2019 the Portuguese government emitted a commitment to achieve carbon neutrality by 2050, representing a fundamental alignment for the evolution of the Portuguese economy. Furthermore, this theme has gained importance since, it could bring financial impacts derived from climate-related risks in the financial system and, on the other hand, investment opportunities arises from the Paris Agreement.

In this context, the countries should also continue taking the lead in mobilizing climate finance from a wide variety of sources, instruments and channels, considering the significant role of public funds, through a variety of actions, including supporting country-driven strategies, and taking into account the needs and priorities. Such mobilization of climate finance should represent a progression beyond previous efforts[1].

This theme, it is also fundamental for the insurance market regulators since the nature of climate-related risks embraces assets and liabilities in the insurance companies. Indeed, there are plausible climate scenarios in which insurers could end up with significant investment losses or significantly higher than expected insurance claims. Thus, the potential financial impacts of climate change are of key relevance to insurance supervisors in the light of their mandate to protect policyholders and safeguard financial stability.

This study is the result of an internship developed in the insurance and pension funds regulator of Portugal, having as objective to highlight benchmarks to monitor climate-related risks, and to estimate the impacts of climate-related risks in the insurance market based on financial stress test and climate-change scenario modelled for Portugal, with the aim to evaluate the risks of turning into a sustainable financial system, driven by the Paris agreement, European targets and local strategic agenda.

[1] Agreements: United Nations Framework Convention on Climate Change (1992), Kyoto Protocol agreement (1997), Kyoto Protocol into effect (2005) and Paris agreement (2015).

I.1 PROBLEM STATEMENT

The stress test developed in this study was possible using Solvency II disclosure, which provides detailed information on the investment of the insurance companies[2]. However, climate-related risks are not incorporated in a clear analytical metric in the disclosure system, because the nature of this risk is different with the assessed by Solvency II (one-year time horizon). Furthermore, the International Financial Reporting Standard (IFRS) does not provide a specific framework to incorporate environmental and social benchmark to monitor sustainable finance.

Therefore, one of the biggest challenges for the global market is to define a disclosure framework to stablish a global and standard climate-relate risk benchmark, this would increase the transparency by enhancing the international comparability, to strengthen the already disclosure system by reducing the information gap and contributing to the economic efficiency by helping investors to identify opportunities and risks across the world.

Additionally, the financial issue in this study is that pricing forward-looking climate risks in financial contracts and portfolios' performance is challenging due to the nature of climate risks. Deep uncertainty and tail effects (Weitzman 2009, 2011), tipping points (Solomon et al. 2009, Lenton et al. 2019) and non-linearity (Ackerman 2017) leading to potential domino effects (Steen et al. 2018) are challenges to define a framework to develop a model for this study. This means that climate transition risks cannot be priced based on historical market data (e.g. to calculate volatility measures), but require to use the information on future climate policy shocks produced by climate economic models. Thus, standard financial risk pricing models (e.g. Merton, 1974; Black and Scholes, 1973; Black and Cox, 1976; Duffie and Singleton, 1999) are not adequate to deal with the complexity of climate-financial risks (Battiston et al. 2016a) because they build on average value and most likely scenario, on assumptions of linearity and normal distributions, and on backward-looking benchmarks that are at odd with the characteristics of climate risk.

[2] EIOPA. Solvency II templates [Online]. Available from: https://www.eiopa.europa.eu/tools-and-data/supervisory-reporting-dpm-and-xbrl_en

This uncertainty is driven by an increasing discrepancy between international ambitions to combat climate change and the actual progress to date. Climate Action Tracker organization reported on 2019 “Brazil: continuous reversal of environmental policies as 2019 breaks records in deforestation”; “China: Third year of emissions growth as coal investments and increased industrial output continue”; “European Union: Cross-sectoral policies, emissions trend moving in right direction, but needs to be faster”[3]. Linked with the decision of the previous elected government of the *United States of America* to withdraw from the Paris Agreement, potentially delaying progress regarding climate ambitions further. This pattern might increase the possibility of climate change[4], so it is necessary to evaluate the climate-related risk under different scenarios, based on whether climate targets are met, and the pathway of this transition (orderly or disorderly).

I.2 RESEARCH QUESTIONS

What are the existing benchmarks for monitoring the interaction between the insurance market and sustainable finance? Since conventional benchmarks do not reflect low-carbon considerations in their methodologies, it is crucial to identify which benchmarks are already applicable to monitor, from a coordinated manner, the interaction between sustainable finance and each component of the value chain of an insurance company. Mainly because, benchmarks have an indirect but important impact on investments, and they also play a significant role and can be a key lever in aligning the investment and analyst community with long-term sustainability considerations and the transition towards a low-carbon economy (EIOPA, 2019).

How to define a reliable assessment of climate-related risks? Does already exist any framework to supervise climate-related risks? In May 2020, the Network for Greening the Financial System (NGFS)[5] released a ‘*Guide for Supervisors: Integrating climate-*

[3] Climate Action Tracker (Dec. 2019), Warming Projections Global Update.

[4] Over the years, there has been a strong consensus within the scientific community in interpreting the goal of holding warming below 2°C to use the “likely below” 2°C class of scenarios in the scientific literature. These energy-economic model scenarios have a 66% chance, or greater, of staying below a 2°C global mean warming above pre-industrial levels throughout the 21st century.

[5] Network for Greening the Financial System (2020). Referencing [Online]. Available from: https://www.ngfs.net/
NGFS is a collaboration of 66 members and 13 observers, including central banks and supervisors. Among them Bank of Portugal, European Insurance and Occupational Pensions Authority (EIOPA), European Banking Authority (EBA), European Central Bank (ECB), Bank of England, and supervisors from all continents as Financial Market Commission from Chile, etc.

related and environmental risks into prudential supervision'. This guide contains five recommendations made for all supervisors to accelerate the efforts in this area. These recommendations rose from '*A call for action: Climate change a source of financial risk'*, NGFS, where it was noted that there is a need for collective leadership and globally coordinated action to better identify transmission channels of climate-related and environmental risks. It is also important to mention that the Central Bank of Portugal and EIOPA are integral members of this network, so by following these recommendations will allow us to align the result of this study with the developed studies by the central bank and supervisors, generating synergy and comparability between the results of different studies.

How to define realistic scenarios in a globally coordinated way? During June 2020, NGFS emitted the '*Guide to climate scenario analysis for central banks and supervisors*', where it is recommended to assess economic and financial impacts derives from climate risks on a wide-ranging set of economic and financial variables (e.g. GDP, inflation, equity and bond prices, etc.) and supervisory reporting data with new climate-related database.

To assess transition risk, should sovereign bonds be included in the stress test? During the last decades Sovereign Bonds have been studied under a perspective of defaultable investment instruments as a consequence of the last geopolitical and economic events of the end of the 20th century. Nowadays, the rating agencies are publishing studies to capture the possible effect that a climate change can spread over the sovereign credit risk, revealing that there are expectancies of a downward pressure on sovereign ratings during the remainder of this century[6] in front of climate change materialization, given the vulnerabilities of individual sovereigns, where the conclusion was lower-rated sovereigns appear as the most exposed and vulnerable economies to be affected. Kling et al. (2018) also assessed the impact of climate risks on sovereign borrowing costs, focusing in the most climate vulnerable low-income countries exposed to physical climate risks. They concluded that countries with higher degrees of climate vulnerability face higher sovereign borrowing costs. In following studies, it was confirmed this idea exposing that climate vulnerabilities have a downward and significant effect on bond yields. In adherence, EIOPA developed a climate risk assessment of the sovereign bonds'

[6] Standard & Poor's Rating Services (2014). Climate change is a global mega-trend for Sovereign Risk.

portfolios of European insurance firms, finding that countries where the level of decarbonization of the economy is low (e.g. Poland) would be exposed to higher climate-related financial risk. This, in turn, could be translated via shocks on sovereign bonds' value to insurance firms' portfolios in Europe (Battiston et al. 2019).

How could climate change affect governments? Governments, both on a national but also sub-national level, are uniquely exposed as they not only have to shoulder the cost of relief and recovery, but also have to pay for the reconstruction of public infrastructure. And when individuals and firms are underinsured, the government is often expected to support private rebuilding efforts by providing transfer payments as well. Closing the protection gap between insured and uninsured losses is thus in the public sector’s vital interest (Swiss Re, 2015).[7] It is relevant to highlight that, without additional government action on climate change adaptation and mitigation, the impact of climate risks on sovereign borrowing costs may become more costly[8].

What would be the volume of the economic impacts of climate change? According to a study carried out by the European Commission’s Centre[9], Joint Research in the absence of measures for adaptation or mitigation, the impact of direct and indirect effects of climate change in Europe over a very long term (2071-2100) could cause annual total damages across the European Economic Area (EEA) of around 190 billion. Considering that the EEA is composed by 31 countries, on average each country could face annual economic losses of 6.13 billion, although, the economic impact will depend on the geographic characteristics of each country.

How would climate change affect Europe? Are there vulnerable areas? 'Natural disaster hotspots' are likely to develop along the following lines: The greatest accumulation of future risks will occur in coastal regions bordering the North Sea such as the British Isles and the Netherlands, which are densely populated and economically pivotal for Europe. Regions in Southern Europe (including the Iberian Peninsula) will see a progressive and strong increase in overall climate hazards. The frequency of riverine floods will triple

[7] Swiss Re (2015). Closing the protection gap. Disaster risk financing: Smart solutions for the public sector.
[8] Imperial College Business School (2018), Climate Change and the Cost of Capital in Developing Countries. Assessing the impact of climate risks on sovereign borrowing costs.
[9] European Commission, Joint Research Centre, JRC Scientific and Policy Reports (2014). Climate Impacts in Europe, The JRC Peseta II Project.

(with current 100-year events occurring roughly every 30 years in the 2080s in Southern France and northern Italy, and perhaps sub-annually in the Danube region); and the frequency of heat waves, droughts and wildfires will increase more than 10-fold in the same period (mainly in Southern Europe). The overall exposure to multiple (independent) hazards shows a positive gradient that is even more pronounced than in single-hazard scenarios (EIOPA, 2019).

To quantify physical risk, should we work with the complete historical database? Or are the last decades a better representation of the future? The increasing concentration of carbon dioxide, methane and nitrous oxide in the atmosphere are unprecedent in at least the last 800,000 years and are extremely likely to have been the dominant cause of warming since the mid-20th century (IPCC 2014). Therefore, in this study it was developed statistical analysis based on different timeframes, with the purpose to evaluate the structural change in the catastrophe probability distribution in Portugal.

Should the outcome of different climate-related risks be combined? Are they comparable? The interrelationship between physical and transition risks is another key factor mentioned by NGFS. Insufficient mitigation policy actions can trigger more intense and more frequent extreme weather events which can in turn spur a disorderly transition. Thus, it is crucial to use scenarios analysis incorporating both, physical and transition risks.

I.3 CHARACTERISATION AND RISK PRESENTATION

I.3.1 Insurance and Pension Funds Supervisory Authority of Portugal (ASF)

ASF has the mission of ensure the well-functioning of the insurance and pension market of Portugal, in order to guarantee the protection of the policyholders, insured persons, participants and beneficiaries. This mission is ensured by the promotion of stability and financial strength of all institution under its supervision, as well as ensuring operators to maintain high standards of conduct.

ASF oversees a variety of risks related with insurance market, in order to strengthen the response in front of the materialization of the well-defined risks in Solvency II. But during the last decades new risks are arising, among others, from geopolitical decisions in front of climate change.

I.3.2 Risk presentation

Climate-related risks refers to financial risks posed by the exposure of financial institutions to physical and transition risks caused by, or related to, climate change, i.e., damages caused by extreme weather events or a decline in asset value in carbon-intensive sectors. Physical risk refers mainly to an increase on the frequency of extreme weather events, such as heat waves, landslides, floods, wildfires and storms. Transition risk refers to the process of adjustment towards a low-carbon economy (emissions must eventually reach the Paris agreement targets[10]). The process of reducing emissions is likely to have significant impacts on all sectors of the economy, affecting financial assets values and potentially impacting financial stability and the economy more broadly. In the context of transition risk, there are recognized three risk drivers, policy risk (the abrupt implementation of stringent policy measures that aim to mitigate the adverse impact of climate change), technological risk (it drives to lower CO_2 emissions but also disrupt parts of the economic system based on fossil fuel) and confidence risk (consumer preferences and confidence on the market and government may decrease due to uncertain future and policy measures).

Environmental risks refer to financial risks posed by the exposure of financial institutions and/or the financial sector to activities that may potentially cause or be affected by environmental degradation, such as the rise of sea levels, rise on the average temperatures, air pollution, water pollution and scarcity of fresh water, land contamination and desertification, biodiversity loss, and deforestation. Therefore, environmental degradation could cascade to risks for financial institutions and governments. For the purpose of this study, the environmental risk is considered as the materialization of climate change, having as consequence the increase in the severity of physical risks. Therefore, in this study, each time physical risk is mentioned, an increase in severity and frequency is considered, as the materialization of environmental degradation.

[10] At COP 21 in Paris, on 12 December 2015, Parties to the UNFCCC reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future.
Paris agreement. Further information [Online]. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement

I.3.3 A brief presentation of the structure of this study

The study presented in this report was based on two pillars: Benchmarks and Stress test scenarios, as shown in Figure 1. These pillars contribute to recognize climate related risk assessment frameworks already developed by relevant institutions, as central banks and supervisors.

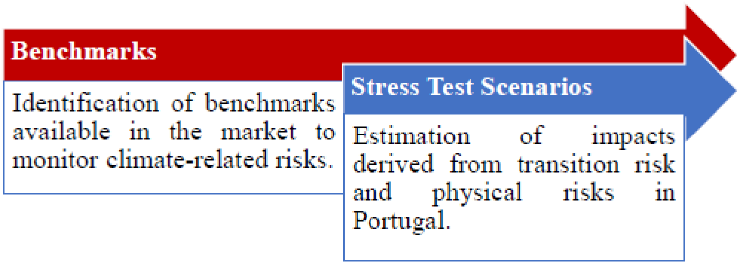

Figure 1: Diagram of the characteristics of this study

The initial step of this study was to identify accurate benchmarks available in the market to monitor climate-related risks, and their application in an insurer's value chain. This section is mainly composed by literature review, in order to list applicable benchmarks.

Secondly, it was necessary to develop a stress test based on coordinated scenarios to estimate the impacts on the insurance market derived from climate-related risks. Nonetheless, in order to develop this stress test, it was necessary to replicate financial stress test methodologies by type of assets, to construct macroeconomic generalized linear models to define local scenarios, and additionally, there were analysed some limitations in the construction of a statistical climate change scenario based on historical data of natural events in Portugal (see annex 1).

II Chapter 2: Benchmarks and Stress test scenarios

This chapter presents two perspectives for monitoring climate-related risk, based on literature on the transition to sustainable finance: Benchmarks availability and Stress test scenarios. These components will allow us to define the approach and framework for this study.

II.1 Benchmarks

The benchmarks presented in this study are identified by their availability, and later in the conclusion, it is suggested its application in the insurer's value chain according the limitations identified.

II.1.1 What is already applicable?

Sustainable development goals (SDGs)[11], Task Force on Climate-related Financial Disclosures (TCFD): Annual Status Report[12] and Green bond indexes[13] are some of the current tools used to monitor the transition into sustainable finance.

Particularly, SDGs were mentioned by the Reflection Group for Sustainable Finance of Portugal[14] in '*Guidelines to accelerate sustainable finance*' issued in July 2019, remarking its relevance.

II.1.1.1 Sustainable development goals

In September 2015, the United Nations adopted 17 Sustainable Development Goals with the purpose to assess the 2030 Agenda[15] for Sustainable Goals. Later, in December 2019, the EU commission presented 'The European Green Deal', where the SDGs are

[11] Sustainable development in the EU: Monitoring report on progress towards the SDGs in an EU context. 2020 edition.
[12] TFCD (June 2017). Recommendations of the Task Force on Climate-related Financial Disclosures.
[13] As Bloomberg Barclays MSCI Green Bond Index, S&P Green Bond Index, BofAML Green Bond Index, among others.
[14] Group composed of the main players in the financial sector in Portugal and coordinated by the Ministry of Environment and Energy Transition in partnership with the Ministry of Finance and Ministry of Economy.
[15] The strategy defines one or more targets in five areas: (1) employment, (2) research and development (R&D) and innovation, (3) climate change and energy, (4) education and (5) poverty and social exclusion (26). The set is structured along the 17 SDGs and covers the social, economic, environmental and institutional dimensions of sustainability as represented by the Agenda 2030.

recognized as an integral part of the Commission's Annual Sustainable Growth Strategy of EU, and it was also reflected in the European Semester country reports and the communication[16].

The EU commission, with the purpose to create mechanism to support damage prevention, concluded that by improving resilience will help safeguard sovereign credit profiles, but also has the potential to increase the rate of return for investment. Overall, they exposed that broad economic, fiscal and social benefits derive from building greater economic and social resilience to climate change.

Annually is emitted a Sustainable Development Report[17] to review the countries' performance on the 17 SDG, where it is included SDG index, rankings, interactive map and country profiles. It is relevant to remark that all this information is available in a database format, being able to develop statistical analysis.

Although, relevant benchmarks are currently being developed, representing a potential contribution to the reduction of information gap.

II.1.2 What is under development?

II.1.2.1 EU Taxonomy Regulation[18]

In June 2020, the EU Taxonomy Regulation was published in the Official Journal of the European Union and entered into force on 12 July 2020. The EU taxonomy is a tool to help investors, companies, issuers and project promoters navigate the transition to a low-carbon, resilient and resource-efficient economy, setting out performance thresholds for economic activities. Indeed, it is consistent with the EU's environmental objectives defined in the EU Green Deal[19].

The EU taxonomy recognizes two type of economic activities that substantially contribute. First, economic activities that make a substantial contribution based on their

[16] EU commission (May 2020). 2020 European Semester: Country-specific recommendations.
[17] UN. Sustainable Development Report [Online]. Available from: https://dashboards.sdgindex.org/
[18] Regulation (EU) 2020/852 of the European Parliament and of the council of 18 june 2020, on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088
[19] The deal aims to transform the Union into a modern, resource-efficient and competitive economy where climate and environmental challenges are addressed and turned into opportunities. It includes a roadmap with actions to move toward a circular economy, stopping climate change, reverting biodiversity losses and cutting pollution.

own performance, e.g., an economic activity being performed in a way that is environmentally sustainable. Second, enabling activities, economic activities that by provision of their products or services, enable a substantial contribution to be made in other activities, e.g., an economic activity that manufactures a component that improves the environmental performance of another activity.

The Taxonomy is based on three performance levels: substantial contribution, significant harm and a middle category of neither substantial contribution nor significant harm.

In the following points an extract of the EU taxonomy regulation published in June 2020 is introduced, in order to align this report to the ASF study n°01/2020[20] where the development of EU taxonomy was presented.

II.1.2.1.1 Environmental objectives

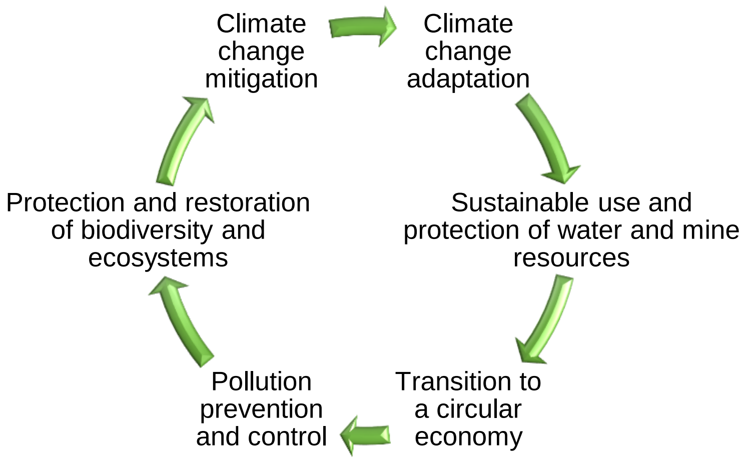

Figure 2: Environmental objectives, EU taxonomy.

II.1.2.1.2 Criteria for environmentally sustainable economic activities:

(a) Contributes substantially to one or more of the environmental objectives,

(b) does not significantly harm any of the environmental objectives,

(c) complies with technical screening criteria that have been established by the Commission.

[20] ASF study n°01/2020 (Jan. 2020) [Online]. Available from: https://www.asf.com.pt/NR/exeres/76113CB9-3B69-48E6-A062-02481688BB31.htm

II.1.2.1.3 Technical screening criteria (TSC)

The technical screening criteria seeks to identify the most relevant potential contributions to the environmental objective, as well as specify the minimum requirements that need to be met to avoid significant harm to any of the relevant environmental objectives. Also, these TSC take into account the potential market impact of the transition to a more sustainable economy.

The TSC will ensure that power generation activities that use solid fossil fuels do not qualify as environmentally sustainable economic activities.

A Platform on Sustainable Finance will be established by the EU Commission, integrated by wide variety of experts, with the objective to receive technical advises on the technical screening criteria; to analyze its impacts; to monitor and generate report regarding capital flows into sustainable investments; among others.

II.1.2.1.4 Scope

This Regulation applies to:

(a) Measures adopted by Member States or by the EU that set out requirements for financial market participants or issuers in respect of financial products or corporate bonds that are made available as environmentally sustainable,

(b) financial market participants that make available financial products,

(c) undertakings which are subject to the obligation to publish a non-financial statement or a consolidated non-financial statement.

II.1.2.1.5 Entry into force and application

(a) in respect of the environmental objectives 'Climate change' mitigation and 'Climate change adaptation' from 1 January 2022; and

(b) in respect of the environmental objectives 'Sustainable use and protection of water and mine resource', 'Transition to a circular economy', 'Pollution prevention and control', 'Protection and restoration of biodiversity and ecosystems' from 1 January 2023.

II.1.2.1.6 Review

By 13 July 2022, and subsequently every three years thereafter, the EU Commission will publish a report on the application of this Regulation.

II.1.2.2 European Actuaries Climate Index (EurACI)[21]

The Board of the Actuarial Association of Europe (AAE) established a Working Group (WG) in 2019 to investigate the feasibility of producing an European Actuaries Climate Index (EurACI). The WG, which includes members from 15 associations, has undertaken a detailed analysis and has had the benefit of discussions with the ACI working group in North America (first ACI release in 2016 in North America), which has helped to identify the key issues to be addressed in developing an EurACI. The WG concluded that the development of an EurACI was feasible, but further work was needed to firm up on data availability and the likely costs of development and maintenance of the index.

The methodology of the ACI is based on analysis of seasonal data for six index components collected since 1961. The index measures changes in extremes of high and low temperatures, high winds, heavy precipitation, and drought, as well as changes in sea level, expressed in units of standard deviations from the mean for the 30-year reference period of 1961 to 1990. Combining six components over a five-year measurement period, the index's moving average smooths out monthly and seasonal fluctuations for a meaningful measurement of long-term climate trends.

II.1.2.2.1 Usage of the index

This Index will provide information on trends in the frequency of extreme events that could be attributed to climate change in EU. Although no final decisions have been taken on how this will be made available, it is likely that quarterly updates will be published on the AAE website, similar to those published by ACI.

Climate indices provide useful information for actuaries, insurers, regulators and policy makers in relation to the frequency of the occurrence of extreme climate events. They do not provide information on the losses which arise due to these events. Nonetheless, the ACI working group are working on the development of an Actuaries Climate Risk Index, which would incorporate information on the losses arising from past events which could be of assistance in setting reserves and capital requirements and indeed pricing for such risks.

[21] Source: Society of Actuaries in Ireland [Online]. Available from: https://web.actuaries.ie/development-european-actuaries-climate-index

This index could be developed by the end of 2020, with the first results being published in early 2021.

II.2 STRESS TEST SCENARIOS[22]

In this point, the selected scenarios for the development of this study are introduced.

II.2.1 NGFS Scenarios

NGFS proposed a scenarios framework classifying them according the 'Transition pathway' and the 'Strength of response', as shown in Figure 3. The transition pathway could be 'Orderly' or 'Disorderly', and the strength of response is based on whether climate targets are met ('Met' or 'Not met'). The orderly and disorderly scenarios explore a transition which is consistent with limiting global warming to below 2°C. While the hot house world scenario leads to severe physical risks.[23] (See annex 2)

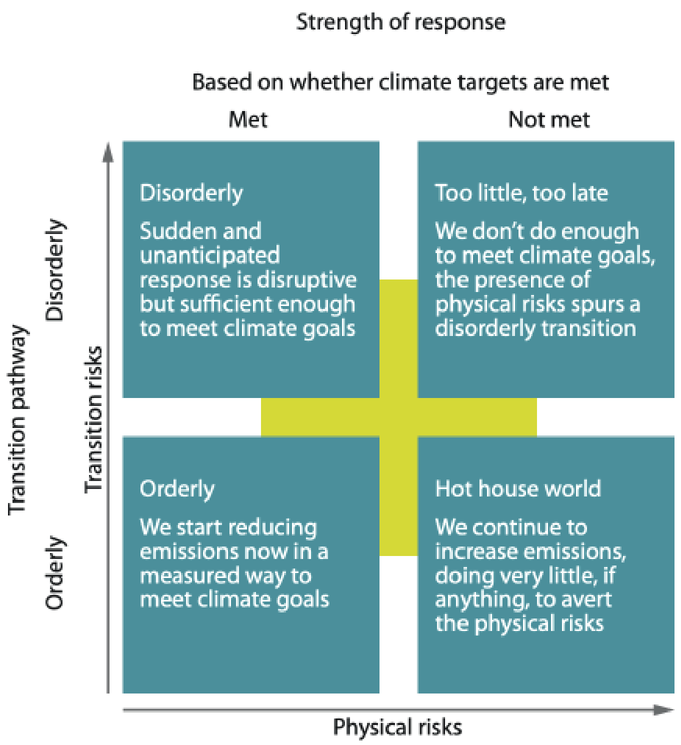

Figure 3: Source: NGFS (2019a). NGFS Climate Scenarios Framework.

[22] NGFS (June 2020) Guide to climate scenario analysis for central banks and supervisors.
[23] NGFS will continue to develop the scenarios to make them more comprehensive, with the aim to be as relevant as possible for economic and financial analysis.

II.2.2 Macroeconomic impacts

In June 2020, NGFS released the document '*The Macroeconomic and Financial Stability Impacts of Climate Change'*, where it recommends the development of granular computational energy-economy general equilibrium models, useful for analysis of the impacts of climate change at the sectoral level. The different demand and supply channels through which climate change can impact the economy could also be spelled out more clearly in macroeconomic models, rather than limiting climate effects to some sectors of the economy (such as energy or agriculture).

Additionally, at the date, NGFS release '*Climate Change and Monetary Policy*' document, being a technical and expert opinion text that contains a description of the key macroeconomic variables that can be affected due to climate-related risks or its mitigation (see annex 3). The macroeconomic effects considered in the development of this study are based on these documents.

III Chapter 3: Transition Risk assessment: methodologies and results

III.1 Local scenarios

The stress test scenarios, used in this study, are also composed by a Portuguese macroeconomic analysis introduced in the following points.

III.1.1 General Linear Models on the Portuguese economy

The application of Generalised linear models to the Portuguese economy intends to understand the structural functioning of the economy, explained by the different macroeconomic variables. The initial macroeconomic variables selected to develop this model were Domestic Demand; Investment (gross fixed capital formation); Value Added; Employment Rate; Labour Force; Multifactor Productivity; energy generation from Renewable Sources and Fossil Fuel. Each variable was applied under annual growth terms, to make them comparable in time, following the nature of the dependent variable Real GDP. The interval of time used to construct these general linear models is from 1985 to 2017 and the selected database source was OECD for the Portuguese economy[24].

After several analysis we reached three accurate general linear models explaining the behaviour of the Real GDP, each of them has estimates with statistical significance higher than 95% (see annex 4), also, it was used the maximum parsimony criterion in order to get the most isolated estimative for each variable[25]:

(1) $Real\ GDP \sim 0.023\ Fossil\ Fuel + 0.013\ Renewable\ Sources + 0.258\ Multifactor + 0.628\ Domestic\ Demand$

(2) $Real\ GDP \sim 0.6890\ Domestic\ Demand + 0.0034\ (Domestic\ Demand \times Renewable\ Souces) - 0.0007\ (Renewable\ Sources \times Fossil\ Fuel)$

(3) $Real\ GDP \sim 0.2498\ Investment + \ 0.3216\ Labour\ Force + 0.1059\ (Domestic\ Demand \times Multifactor)$

[24] OECD (2020). Annual country statistical profile [Online]. Available from: https://data.oecd.org/portugal.htm

[25] Maximum parsimony criterion was used in order to do not over complicate the general linear models; otherwise multiple multiplicative effects are suggested to be applied in the models.

From these models we can obtain some conclusions about the expected Real GDP behaviour over time in equilibrium terms, first, carbon intensive energies have had a positive isolated effect on the economy growth, as well as the renewable sources generation in a lower scale, given the progressive distribution of energy generation.

Second, in GLM 2 we can see a positive estimate for the multiplicative interaction between Domestic Demand and Renewable Sources. This estimate represents the positive sensitivity produced by this interaction on Real GDP of Portugal during the analysed period, following the hypothesis of sustainable economic growth.

Although, there is a negative sensitivity between Fossil Fuel and Renewable Sources of energies, this is naturally explained by the negative correlation revealed between these variables during the analysed period. This negative correlation is expected to persist over time, following the target trajectories that the government has suggested to reach carbon neutrality.

GLM 3[26] was obtained for showing us an approximation of how the economy may react under a negative or positive effect on these explanatory variables, in attempt to construct integrated macroeconomic scenarios. No energy variables are considered in this GLM.

III.1.2 Macroeconomic impacts

In local terms, this study follows the compromise of the Portuguese government to decrease carbon energy consumption by sector, as exposed in the '*Roadmap for Carbon Neutrality 2050'* (RNC). Furthermore, the positive and negative effects on the Real GDP derived from this transition are included, assuming the economy is indeed absorbing both transition effects[27], therefore, the macroeconomic local model allows us to define the level of Real GDP at risk affected by a specific macroeconomic variable.

Thus, the scenarios are composed by two dimensions, NGFS scenarios, macroeconomic effects and database, and the macroeconomic model developed for Portugal (some local adjustments are defined in each scenario based on the RNC 2050, see annex 5).

[26] It was not used the Employment Rate variable because no representative regression was obtained. Nevertheless, the Labour Force and Employment Rate have a Pearson correlation of 0.85.
[27] Recommendations of the Task Force on Climate-related Financial Disclosures, 2017 (Climate-Related Risks and Potential Financial Impacts, Table 1, p.10-11).

III.2 Stress test by type of financial asset

By using stress test scenarios, it was possible to study the financial impacts on Stocks, Corporate bonds and Sovereign bonds, derived from transition risk materialization. For this, the asset valuation was developed by replicating public methodologies developed by different institutions, central banks and supervisors.

III.2.1 Characterization of the stress test

III.2.1.1 Sectors

This stress test works on 20 industries categorized by SIC codes[28], assessing the level of vulnerability of each sector. Intuitively, energy transition risk is more impactful for industries that rely heavily on fossil fuels. Hence, Insurance companies may be more or less vulnerable to energy transition risks depending on their exposure to more or less vulnerable industries.

III.2.1.2 CO_2 by sector

Annually, the participating countries of international commitments under the United Nations Framework Convention on Climate Change (UNFCCC) and EU commission, must report the levels of greenhouse gases emitted from 1990 to nowadays. In Portugal, this report is developed by the Portuguese Environment Agency[29] and shows us the levels of greenhouse gases by sector in Portugal, as shown in Figure 4:

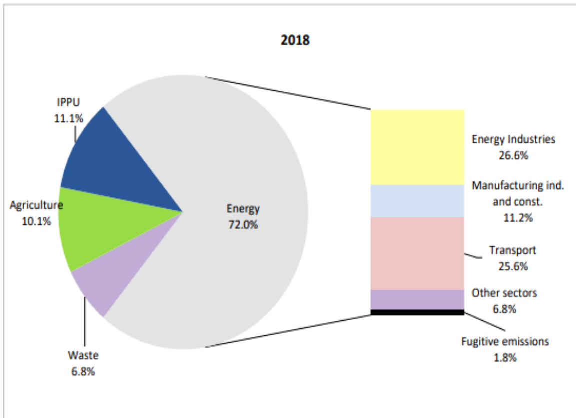

Figure 4: Greenhouse gases emission in Portugal[30].

[28] SIC codes [Online]. Available from: https://www.siccodes.net/

[29] Agência Portuguesa do Ambiente. National inventory report [Online]. Available from: https://apambiente.pt/

[30] Industrial Processes and Product Uses (IPPU)

‘Other sectors’ category includes all other sectors that are not specified in the previous graph. Therefore, we distributed this proportion in same parts among the others and less carbon intensity sectors, with the purpose to maintain the logic that this transition is an effort made for all of society, with possible financial and economic consequences.

III.2.1.3 Investment portfolio

Figure 5 shows the structural distribution of the investment portfolio of the insurance market of Portugal for the last quarter of 2019. Specifically, this stress was applied on Sovereign bonds (43%), Corporate bonds (Corporate bonds plus Structured products, 28%) and Stocks (7%).

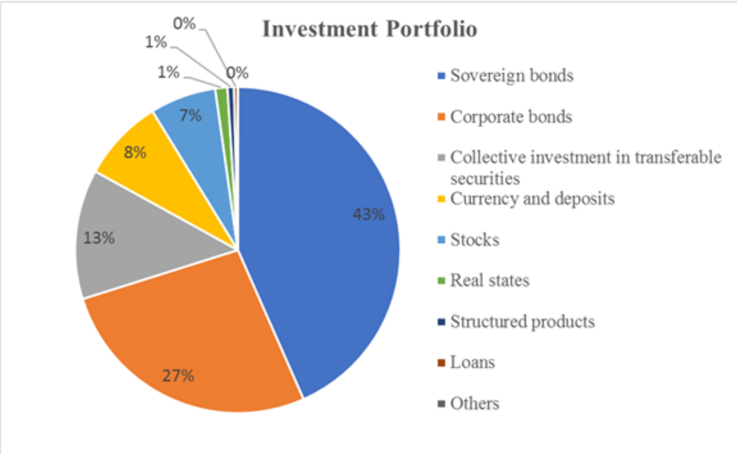

Figure 5: Investment portfolio of the Insurance Market of Portugal.

III.2.2 Asset valuation methodologies and results

III.2.2.1 Stocks

In 2018, De Nederlandsche Bank developed an energy transition risk stress test[31] for the financial system of the Netherlands, where was proposed a Transition Vulnerability Factor (TVF) methodology[32], based on the value added (macroeconomic variable) and CO_2 emission as driver variables of climate risk. This approach has the advantage that the selected variables are coherent to determine vulnerability related to climate risk, since the more CO_2 emitted, the higher is the risk and consequently the higher is the TVF; on the other hand, the more value added generated by a sector, the higher is the capacity of

[31] De Netherlandsche Bank (2018). An energy transition risk stress test for the financial system of the Netherlands.

[32] De Nederlandsche Bank (2018). Web-appendix: Modelling the energy transition risk stress test, pp. 17-21.

resilience, and the smaller is the TVF. Later, they use the TVF as betas in CAPM[33] in order to reflect the systematic risk that is not potentially considered into the asset valuation.

Before continuing applying this methodology, we analysed the historical evolution of this theory, with the purpose to corroborate its application in the study of transition risk (annex 6).

Despite of the convenience of this approach, it is also imperative analyse it under a theoretical standpoint, with the purpose to assess the financial coherence, in order to define if it is applicable in this study or not.

III.2.2.1.1 Beta as our financial benchmark

First of all, the beta baseline proposed by DNB was the percentage of value added that a sector contributes to the total value added generated by the country. Following this approach, we are assuming that the systematic risk, in a baseline scenario, is well-represented by the capacity of generate value. This can be represented by the value added[34] generated by the sector S in the country C:

$$(4)\ \beta_{baseline} = exp\ (\%Value\ added\ by\ S\ in\ C) = \ exp\ \left(\frac{Value\ added(C,S)}{Value\ added(C)}\right)$$

On the other hand, the climate systematic risk proposed by DNB was to incorporate the CO_2 emissions by each sector, as we mentioned above. In fact, we kept the assumption that transition risk is naturally and positive correlated with the levels of CO_2 emitted by each country or sector, then our climate systematic risk is represented by:

$$(5)\ \beta_{CO2} = exp\ \left(\frac{\frac{CO2(C,S)}{Value\ added(C,S)}}{\frac{CO2(C)}{Value\ added(C)}}\right)$$

Consequently, we can see that the beta is composed by the relationship between the CO_2 emitted by sector S per unit of value added generated by the sector S, divided by the CO_2 emitted per unit of value added generated by the country C. In other words, the higher is

[33] Sharpe, Lintner and Mossin, 1964. CAPM: $R_i = R_f + \beta_i (R_m - R_f)$. Where, Ri is the expected return of a risky asset, Rf is the risk-free interest rate, Rm the expected market return, and βi is the systematic risk.
[34] Source: National Institute of Statistics of Portugal (2020). Statistical Yearbook of Portugal – 2019 [Online]. Available from: https://www.ine.pt/

the energy efficiency of the sector S (less CO_2 emissions to generate the same level of value), the lower is the systematic risk analysed.

But rather than obtain an expected asset return, we are interested in obtaining the expected market return (R_M) in order to stress the industrial sectors, regardless of the expected return of the risky asset (Ri). For this, we used the inverse method in the CAPM formula to obtain an expected market return in a baseline scenario and in the scenario where the energy efficiency defines the systematic risk.

(6) $R_M = \frac{R_i - R_f}{\beta} - R_f$

Therefore, the lower is beta (higher levels of energy efficiency, for β_{CO2}), the higher is the expected market return.

Finally, the difference between these R_M will allows us to determine an expected Loss Given Transition (LGT) in the expected market return derived from climate-related risk.

(7) $Loss\ Given\ Transition\ (\%) = \frac{R_M(P) - R_M(baseline)}{R_M(baseline)}$

III.2.2.1.2 Delimitation, limitation and advantage

The main difference between the DNB methodology and the one used in this study is the exponential scale used to calculate the betas, because by working with very small numbers it gives us homogeneity in the severity of the stress, therefore by using exponential properties allows us to highlight those carbon-intensive sectors and subsequently, more exposed to the transition risk, and at the same time smoothing the negative effects for those less carbon intensive sectors.

Furthermore, the exponential scale allowed us to identify positive opportunities for those sectors or countries that are more advanced in this matter. Derived from quantitative analyses in this model, we can conclude that a positive or negative effect will depend on the following inequalities:

- If $\beta_{CO2} > \beta_{baseline}$, then the sector (or country) may have a negative effect derived from this transition.
- If $\beta_{CO2} < \beta_{baseline}$, then the sector (or country) may have a positive effect derived from this transition.

From this quantitative analysis of the behaviour of β_{CO2}, we noticed that these inequalities highlighted the most critical sectors, because for those carbon-intensive sectors (such as energy) the effect derived from our calculations is always negative, regardless of the level of CO_2 emitted by the sector, because there is still a relevant concentration of CO_2 emissions and low energy efficiency exposed by the applied methodology. On the other hand, for those sectors that are less carbon-intensive, if CO_2 levels are reduced, the sector will have higher chances of obtaining a positive effect derived from this transition, because at a specific point β pass from the first inequality to the second one.

As aforementioned, the way to reduce the risk represented by this factor is via increasing energy efficiency, in order to minimize the level of CO_2 emitted to generate value added. Therefore, later the definition of an efficiency-elasticity will be based on this criterion.

Finally, it is relevant to remark that the information about CO_2 emission by each sector in Portugal used in this study is limited to that shown in Figure 4, and on the other hand the applied categorization is composed by 20 industries, therefore, the remaining levels of CO_2 emissions without a specific category are equally distributed among the sectors not specified in Figure 4, following the idea that this transition could affect all sectors. Indeed, neither indirect emissions are assumed nor are scientific environmental knowledges because was prioritized no overcomplicate this methodology.

III.2.2.1.3 Results

The financial impact is determined by using the methodology set out in equation (7), to assess a decrease in the expected market return of each sector, derived from the systematic climate-risk. Table 1 shows the results after all the above mentioned.

Table 1: Stress level by sector in Portugal.

Level of stress after using financial and macroeconomic considerations	%		
Sector	**Orderly**	**Disorderly**	**Too little,**
A - Agriculture, forestry and fishing	-13.2%	-13.2%	-15.6%
B - Mining and quarrying	-58.2%	-90.4%	-15.6%
C - Manufacturing	-6.2%	-12.1%	-15.6%
D - Electricity, gas, steam and air conditioning supply	-58.2%	-90.4%	-15.6%
E - Water supply; sewerage; waste management and remediation activities	-24.0%	-46.8%	-15.6%
F - Construction	-13.9%	-27.2%	-15.6%
G - Wholesale and retail trade; repair of motor vehicles and motorcycles	-9.9%	-19.3%	-15.6%
H - Transport and Storage	-11.9%	-23.3%	-15.6%
I - Accommodation and food service activities	-2.2%	-4.3%	-15.6%
J - Information	-3.9%	-7.7%	-15.6%
K - Financials			
L - Real estate activities			
M - Professional Scientifical and Technical Activities	-3.5%	-6.8%	-15.6%
N - Administrative and support service activities	-3.5%	-6.8%	-15.6%
O- Public Admin. Defence, Compulsionary Social Security			
P - Education	-3.5%	-6.8%	-15.6%
Q - Human Health and Social Work	-3.5%	-6.8%	-15.6%
R - Arts, cultural, entertainment, gamling, betting, recreation	-3.5%	-6.8%	-15.6%
S - Other repairing and personal activities	-3.5%	-6.8%	-15.6%
Em branco	-3.5%	-6.8%	-15.6%

In total terms, the impact on stocks after applying the above stress by sector is presented in Figure 6.

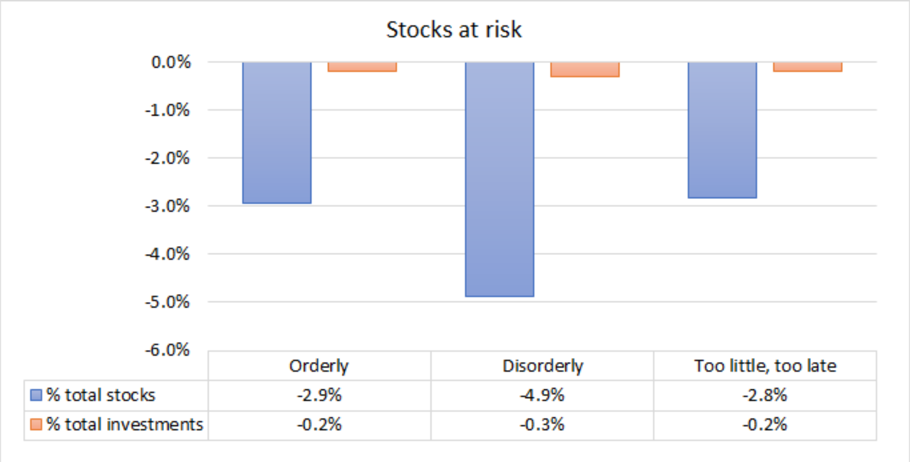

Figure 6: Stress in stocks as a percentage of the total stocks and total investments of the investment portfolio.

III.2.2.2 Corporate Bonds

To analyse this topic, we used the De Nederlandsche Bank methodology, presented in "*A top-down stress testing framework, DNB*" (By T. Daniëls, et al., 2017). One of the ways that bond prices are affected is by changes in the credit risk spread. When the credit risk of a particular bond increases, investors demand a higher return on that bond, which increases the credit risk spread and leads to a drop in the bond price. The change in the credit risk spread of a bond is calculated by industry, as more vulnerable industries will likely have a larger increase in credit risk than less vulnerable industries (R. Vermeulen, et al., 2018)[35].

III.2.2.2.1 Spread stress model[36]

The model adapted is based on ratings migration approach for bonds. For this, it was used a transition matrix developed by S&P[37], that contains the average probability during 1981-2019 of a corporate retaining its rating, moving from one rating class to another, or moving into default. Therefore, in this methodology we had to estimate how the transition matrix changes due to the stress scenario and specific sector.

(9) $$Matrix_{\mathrm{t,stress}} = Matrix_{baseline} \times \sigma_{Matrix(baseline)} \times \varphi$$

Where $Matrix_{baseline}$ is the business-as-usual transition matrix, $\sigma_{Matrix(baseline)}$ is the standard deviation of each cell in the baseline matrix, and φ is a stress factor which is determined by the economic cycle defined in our stress test (different of systematic climate-risk factor).

This stress factor is a multiplication factor for off-diagonal cells. In the case of a stress scenario, we add the stress factor multiplied by the cell's standard deviation to a cell's value in the cells to the right of the diagonal. This increases the probability of migrating from a relatively good rating to a worse rating. The procedure ensures that all row sums remain equal to a hundred percent and that all values in the matrix are larger or equal to zero.

To determine the value of a macroeconomic stress factor, φ, it was estimated an insolvency equation for the Portuguese economy. That is, the equation models the average insolvency probability of Portuguese companies in a specific cycle. Here the insolvency

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[35] R. Vermeulen, et al. De Netherlands Bank (2018). An energy transition risk stress test for the financial system of the Netherland.

[36] T. Daniëls, et. al. De Netherlands Bank (2017), A top-down stress testing framework.

[37] We selected this rating agency with absolutely independency between the rating agencies and the supervisor.

S&P. 2019 annual global corporate default and rating transition study [Online]. Available from: https://www.spglobal.com/ratings/en/research/articles/200429-default-transition-and-recovery-2019-annual-global-corporate-default-and-rating-transition-study-11444862 probability is calculated by dividing the number of insolvencies in a specific period by the total number of companies in the local economy.

Then, two quantile regressions for the insolvency probability were developed using the Real GDP and annual average PSI-20 as explanatory variables, since the PSI-20 represents an appropriate benchmark index of the Portuguese stock market (which are both statistically significant in all of our regressions, see annex 7). The 50th percentile was determined as the baseline and 75th percentile as the stress equation. This leads to the following equations already expressed in %:

(8) $P(Insolvency)_{Median,t} = 7.501 - 0.716 * \ln(PSI20_{t-1}) - 0.049 * Real\ GDP_{t-1}$

(9) $P(Insolvency)_{Stress,t} = 9.213 - 0.890 * \ln(PSI20_{t-1}) - 0.075 * Real\ GDP_{t-1}$

There are two important observations and differences between these regressions to be pointed out. First, the constant is higher in the stress equation. Assuming no real GDP growth and no change in equity prices, ceteris paribus, the equilibrium insolvency probability is about 23% larger in stress condition. Second, the coefficients on the economic variables are larger in absolute terms in the stress equation, therefore a negative effect in the GDP or stocks will be translated in a higher probability of insolvency.

With phi, it is possible to link changes in the insolvency probability to changes in the default probability of the transition matrix. Also, phi is calibrated by the deviation of insolvency probability of the last year compared with its cycle mean.

(12) $\varphi = 1.23 * deviation\ of\ the\ economy's\ insolvency\ probability\ from\ its\ mean$

Then, the change in credit spread is therefore given by the difference between the new and old probability of default. Therefore, when the residual maturity is longer than one year, the cumulative change in the probability of default can be calculated according to the following formula[38]:

(13) $Cumulative\ \Delta PD = \sum_{t=1}^{T} (1 - \Delta PD_{t-1})^{t-1} * \Delta PD_t$

[38] R. Vermeulen, E. Schets, M. Lohuis, B. Kolbl, D. Jansen and W. Heeringa, Web-appendix: Modelling the energy transition risk stress test, DNB (2018).

Where ΔPD_t stands for the difference between the new and old probability of insolvency in year t, and T is the residual maturity.

Finally, in this methodology the value of each bond from the change in credit spread is represented by:

(14) $$V_{New} = V_{Old} * (1 - Cumulative\ \Delta PD)$$

Note that, in order to not overcomplicate the calculation, DNB suggests ignoring the coupon payments of the bonds.

Besides, to reflect that industries which suffer very large equity losses also suffer a large deterioration in credit quality, it is applied the additional step of linking industry specific stock returns to credit rating downgrades. Specifically, a bond whose issuer is in industry i receives a one notch downgrade (e.g. from A- to BBB+) if industry i's stock price decreases by more than 20 percent, defined by the stress test applied on stocks. In case the stock price decreases by more than 30 percent the rating downgrade is two notches, by more than 40 percent three notches, etc. Consequently, a rating downgrade will further increase the change in the credit risk spread calculated in this stress test.

III.2.2.2.2 Risk-free interest rate stress test

Another important driver of bond price is the change in the risk-free interest rate. When the risk-free rate increases, investors demand a higher return on their bonds, which results in a drop in the bond price. We use the projected changes in 10-year government bond yields as a proxy for the change in the risks free rate at all maturities.

To do this, we stress the risk-free yield curve by assuming a linear shift, corresponding to the shift in the yield of 10-year government bonds. Each scenario assumes different linear shift based on the possibilities exposed in annex 3.

III.2.2.2.3 Results

Figure 7 shows the impacts on corporate bonds in total terms.

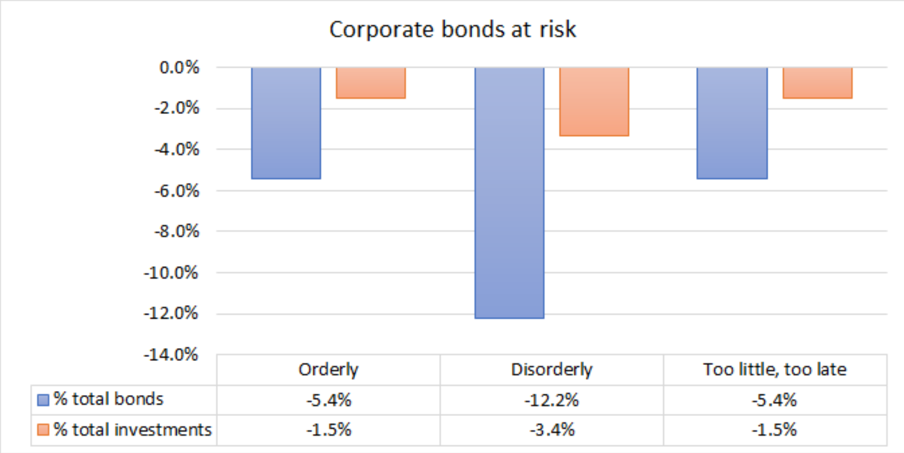


Figure 7: Stress on Corporate bonds as a percentage of the total corporate bonds and total investment.

III.2.2.3 Sovereign bonds

For this type of investment, it was used the methodology developed by S. Battiston in "*A climate risk assessment of sovereign bonds*" (version March 11, 2020), and published by EIOPA[39]. This approach was selected because it combines climate economics modelling, financial risk analysis rooted on network theory, and financial risk pricing under deep uncertainty.

III.2.2.3.1 Climate shocks in the pricing of defaultable sovereign bonds

Based on the motivations discussed in Battiston's study, we consider a defaultable sovereign bond issued at time t_0 and with maturity T. For the sake of simplicity, this methodology illustrates the derivation in the basic standard case of a zero-coupon bond with constant risk-free rate, constant yield and with exogenous recovery rate Rj.

The default probability is denoted as q = P(τ < T), and τ is the time of default. In case of default, the bond pays a recovery rate Rj, defined as fraction of its face value. The expected unitary value of the bond at t_0 can be written as

(15) $$v_j = e^{-r_f(T-t_0)}(1 - q_j + q_j R_j)$$

where r_f is the risk-free rate. The yield of the bond is defined as

(16) $$r_j = -\frac{1}{(T-t_0)} \log\left(1 - q_j\left(1 - R_j\right)\right)$$

[39] S. Battiston, P. Jakubik, I. Monasterolo, K. Riahi, B. van Ruijven (2019). Climate risk assessment of the sovereign bond portfolio of European insurers.

The spread of the bond is the difference between the bond yield and the risk-free rate $r_j - r_f$. The probability of default q_j is obtained from public studies of rating agencies[40], and defined as 40%.

According with Battiston et al. (2020) we can compute the change in value of the bond as[41]:

(17) $$\Delta v_j(P) = e^{-r_f(T-t_0)} e^{r_j(B)(T-t_0)} (e^{\boldsymbol{\Delta r_j(P)}} - 1)$$

Where r_f is the constant free interest rate, rj(B) is the yield of the bond in a baseline scenario defined by equation (16), and $\Delta r_j(P)$ represents the change in the yield of the bond derived from different scenarios.

This change in yield was defined (in our model) as a risk metric to reflect the progress made by each country to achieve the EU targets and Paris agreement. It was defined as:

(18) $$\Delta r_j(P) \approx -\chi_j(P) \times LGT_j \times \frac{VA_j(S)}{VA_j}$$

Where, χ_s represents the elasticity of the transition risk of the country j and scenario P based on the EU targets for the period 2021-2030. LGT_j represents the loss given transition risk in country j, and the last term correspond to the percentage of value added by sector S in the country j.

III.2.2.3.2 Delimitations: Shock by country and elasticity

With the aim to maintain the concordance between the different methodologies applied in this study, the *LGT* exposed in equation (18) is obtained from equation (7) in a national and global level, comparing the value added and levels of CO_2 emissions by country with the total value added and emissions in the world, determining a national market impact.

It is also expected the investor knows that the sovereign entities issuing bonds have committed to achieve certain climate targets for the period 2021-30, exposed in the National Energy and Climate Plans (NECPs) informed by each country by June 12, 2020 (last version).

Thus, the elasticity calculated in this study seeks to reflects the efforts made by each country, understanding that, if until the latest information available, country j presents

[40] Sovereign Foreign Currency Cumulative Average Default Rates (1975-2018) and Sovereign Local Currency Cumulative Average Default (1993-2018). 2018 Annual Sovereign Default and Rating Transition Study. S&P Global Ratings.

[41] See more details in document developed by Stefano Battiston and Irene Monasterolo. 'A climate risk assessment of sovereign bonds', version March 11, 2020.

considerable improvements in renewable energies, it will have fewer impacts due to energy transition in its economy, or in some cases, it can be obtained economic advantages due to high levels of value generation. Since this study is defined under an economic cycle, the elasticity was defined following the 2030 EU frameworks[42] (see annex 8).

III.2.2.3.3 Results

These results can be illustrated by country, allowing us to identify the impact of a transition risk in each country based on its current efforts, as shown in Table 2. For those countries that are already advanced in the Paris agreement targets and decarbonization on its economy, a positive result was obtained. However, these positive cases are represented by a small percentage, which gives us signs of potential benefits derived from this transition.

Table 2: Stress level by country on average.

Country	Orderly %	Disorderly	Too little, too late
AUSTRIA	0.08%	-1.13%	-0.93%
BELGIUM	-4.67%	-6.47%	-0.93%
FRANCE	-1.47%	-2.84%	-0.93%
GERMANY	0.01%	-2.20%	-0.92%
GREECE	-7.70%	-13.13%	-0.95%
IRELAND	-1.09%	-2.68%	-0.93%
ITALY	0.01%	-0.48%	-0.94%
LUXEMBOURG	0.02%	0.00%	-0.92%
NETHERLANDS	-5.57%	-6.99%	-0.93%
PORTUGAL	0.06%	-3.85%	-0.94%
SPAIN	0.01%	-5.78%	-0.93%

Nevertheless, according the equation (17), shocks on each bond depend on its specific characteristic; maturity term, spread and yield. Thus, the concentration of sovereign bond issued by in country j defines the final level of stress on the total sovereign bond in the investment portfolio. Figure 8 shows the value of sovereign bonds at risk as a percentage of total sovereign bonds and total investments:

[42] European council conclusion: Modelling for the 2030 framework. https://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf

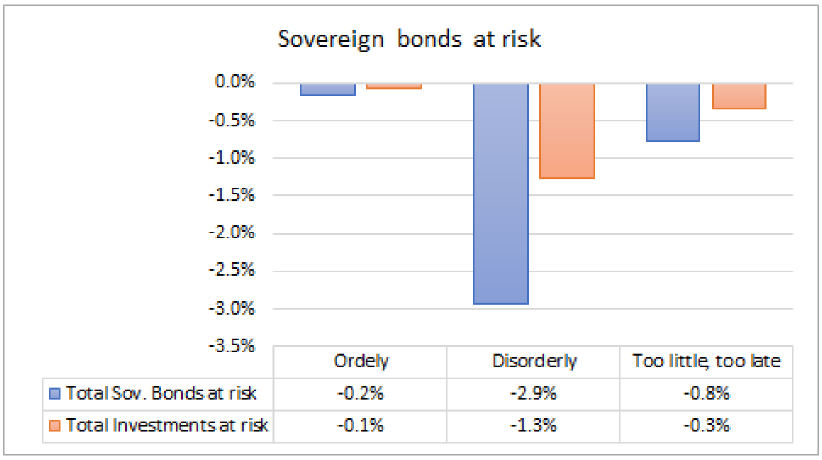


Figure 8: Stress test on sovereign bonds as a percentage of the total sovereign bonds and total investments.

IV CHAPTER 4: PHYSICAL RISK ASSESSMENT: METHODOLOGIES AND RESULTS

IV.1 CHARACTERIZATION OF CLIMATE CHANGE AND SOLVENCY II

Before developing the statistical analysis, it is necessary to characterize the insurance market's consideration of climate-related risks included in their best estimates, as well as what EIOPA says about Solvency II in the face of climate change.

IV.1.1 Valuation of liabilities and pricing

During a consultation developed by EIOPA in 2019, a substantial majority (over 75%) of the groups and insurance companies that provided evidence do not take explicit account of climate or sustainability risks in their best estimate calculations. A substantial number of respondents indicated that they consider that any climate change-related trends are implicitly captured by historical loss data.

Additionally, insurers provided a number of explanations for not doing so, including:

a) Nature of non-life insurance business: Short term duration of non-life contracts (typically 12-month contracts); and the ability to re-price contracts annually, which means that pricing is usually done for a short time horizon.
b) Climate change uncertainties: Lack of understanding of climate change impact; no validated climate change model available in the market; and lack of transparency to which extent current third-party CAT models include climate change.

Therefore, later in this chapter, the elements used for modelling are evaluated, in order to identify possible limitations.

IV.1.2 Solvency capital requirement derived from catastrophic events

EIOPA considers that the current Solvency II framework does not impede the integration of current developments related to climate change in the calibration of the standard parameters for the natural catastrophe risk module of the standard formula. In fact, regular calibration of the standard parameters for the natural catastrophe risk module of the standard formula is developed (each three to five years).

However, EIOPA notes that current capital requirements have been calibrated based on the available historical data for past events. Sustainability developments and, in particular climate change risks, are expected to materialise over the next decades. Such expected fluctuations need to be captured in the risk management strategies in a forward-looking manner in the 'Own Risk and Solvency Assessment' (ORSA).

In adherence, EIOPA recognized that the medium to long-term impacts of climate change cannot be fully captured in the Solvency II capital requirements, which are designed to reflect the risks that insurance companies are exposed over a one-year time horizon. However, EIOPA does not consider that this time horizon should be changed, but rather complementary tools such as scenario analysis and stress testing should be developed.

Indeed, it is important to keep in mind that the Solvency Capital Requirements contains a risk margin added on top of the best estimate to ensure transferability of the liabilities, and capital requirements should cover unexpected losses. But climate variability and uncertainties related to climate change or to the regional impact of extreme weather events due to climate change may impact on the capacity of the insurance industry to capture sufficiently the future developments in their underwriting practices (EIOPA, 2019).

As an empiric example, a number of insurers and especially reinsurers failed in the aftermath of Hurricane Andrew, which made landfall as a category four hurricane in south Florida in August 1992. They failed principally because they had been relying on loss data from the previous two decades for pricing, reserving and so on (Calder et al., 2012). Therefore, the following analysis is based on different timeframes, in order to analyse the effect of using different periods of the historical information of Portugal.

IV.2 Framework for modelling risk from extreme weather events[43]

The impacts of extreme weather events are often evaluated based on their risk, which consists of three elements: exposure, hazard probability and vulnerability (Kron, 2005) (see annex 9). Exposure is the value of assets and the population exposed to extreme

[43] Insurance of weather and climate-related disaster risk: Inventory and analysis of mechanisms to support damage prevention in the EU. 2017, European Commission.

weather events; hazard is the extent and intensity of the disaster event itself; and vulnerability is the susceptibility to damage.

Nevertheless, for the purpose of this initial analysis, only hazard elements were evaluated from an actuarial scope. And the database selected to develop this analysis was EM-DAT database[44].

IV.2.1 Hazard Probabilities

In order to obtain the empirical probability distribution by type of catastrophic event in Portugal, historical information was used with different timeframes, the past 81 years and 31 years, with the purpose to assess the change in the annual frequency distribution of each event.

Table 3 shows that, indeed, an increase in the frequency distribution is obtained when the 31-years database is used instead of the 81-years. Moreover, the 81-years database presents higher probabilities of 0 natural events.

Table 3: Empirical frequency probability distribution using the last 81 years database, compared with the empirical frequency probability distribution using the last 31 years database.

	Climatological		Hydrological		Meteorological	
n° of CAT per year	81 years	31 years	81 years	31 years	81 years	31 years
0	83%	68%	85%	74%	84%	61%
1	14%	26%	12%	23%	11%	26%
2	4%	6%	2%	3%	5%	13%
3	0%	0%	0%	0%	0%	0%
4	0%	0%	0%	0%	0%	0%
Mean	0.21	0.39	0.17	0.29	0.21	0.52

Additionally, as was mentioned in point I.2, according IPCC the levels of CO_2 emitted since the mid-20th century are extremely likely to have been the dominant cause of global warming. Therefore, the timeframe used in modelling, underwriting or pricing will be determinant in terms of the output of the frequency distribution.

[44] This database was selected to develop this model, since it brings us a detailed dataset information about catastrophic events categorised by Natural (subcategorized by geophysical, meteorological, hydrological, climatological, biological and extra-terrestrial), Technological and Complex disaster. The information is available by geographic region, allowing us to assess the tendency of each catastrophic event during the last decades in the world, Europe, and specifically in Portugal. [Online] available from: https://public.emdat.be/

IV.2.1.1 Severity

To obtain a proper representation of the loss tendency due to CAT events, EIOPA proposed to calculate it as the sum of the aggregate disaster losses for the cases studied, corrected for inflation and normalise it. The following equation presents the normalisation process based on Neumayer and Barthel (2011), which accounts for inflation, population and wealth changes.

$$Loss_{i,t}^{Normalised,T} = \frac{wealth_{i,T}}{wealth_{i,t}} \times \frac{population_{i,T}}{population_{i,t}} \times \frac{GDP\ deflactor_{i,T}}{GDP\ deflactor_{i,t}} \times Loss_{i,t} \quad (28)$$

Where, T represent the base year.

Figure 9 shows the historical economic losses due to natural events after the normalize methodology presented in Equation (28):

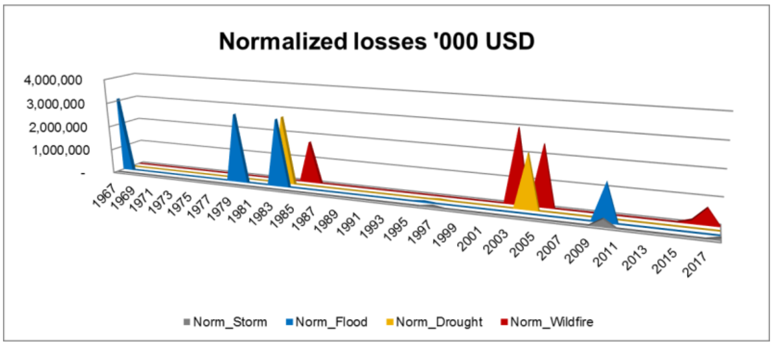


Figure 9: Normalised total damage in Portugal.

From the normalised losses, Storms (meteorological) and Wildfires (climatological) events show increasing linear trends in its severity, Floods (hydrological) have a decreasing tendency, and Drought (climatological) events do not show a clear trend through the time in its severity.

IV.2.1.1.1 CAT modelling analysis[45]

The CAT modelling industry is full of terminology and acronyms, therefore, in this point we examined some of the elements commonly analysed in this process.

By using historical information, we can see, as presented in Table 4, that the coefficient of variation between these two timeframes is significantly lower for Climatological and

[45] The Review Worldwide Reinsurance (2008). A guide to catastrophe modelling.

Meteorological events by using the 31-years database, and on the other hand, Hydrological events shows a lower difference. In other words, by using an 81-years timeframe, we are working with a wider variation in the distribution of the data.

Table 4: Annual Average Losses (AAL) 000' USD, Standard deviation (Sd), Coefficient of variation (CV), using 81-years and 31-years historical information. (see details in Annex 10)

	Climatological		Hydrological		Meteorological	
	81 years	31 years	81 years	31 years	81 years	31 years
AAL	33,139	104,170	21,775	14,426	1,212	7,790
Sd	282,415	502,089	243,658	147,323	16,594	42,329
CV	8.5	4.8	11.2	10.2	13.7	5.4

This wider variation in the distribution of the data might contribute with higher levels of ambiguity in the selection of the timeframe, and ambiguity tends to result in higher premiums than those charged for equivalent, unambiguous risks (Hogarth and Kunreuther, 1989).

Nonetheless, for the following analysis it is relevant to remark that the different risk aversions that the insurers apply in pricing processes was not analysed, rather a fixed risk aversion is assumed to evaluate whether the use of different timeframes contribute to under or overvaluation.

Thus, in order to expose the impact that these timeframes could have, for instance in pricing, we calculated the straightforward premium principle based on the standard deviation of each type of event, assuming a risk aversion of 0.5, presented in table 5.

Table 5: Standard deviation premium principle.

	Climatological		Hydrological		Meteorological	
Premium	81 years	31 years	81 years	31 years	81 years	31 years
Sd principle	174,346	355,214	143,604	88,087	9,509	28,955

Based on these results, we can conclude that by using 31-years in Climatological (Drought and Wildfires) and Meteorological events (Storms), the higher AAL and Sd are determinant in obtaining a premium twice and three times greater, respectively. On the other hand, Hydrological events (Floods) presented the opposite behaviour explained mainly because the AAL and Sd are lower by using 31-years database, being concordant with the tendency of the economic losses of CAT events.

But, if we consider the wider variation on 81-years distribution, it is intuitively that insurers include the wider variation in pricing. To confirm this idea, in study developed by Hogarth and Kunreuther (1992), through mail survey of actuaries, some structured evidence was provided from a subset of respondents who provided written comments that gave insight into their decision processes. Most of these responses indicated that actuaries first anchored the premium on the expected loss, and the majority of these would then, when informed the probability of loss was ambiguous, explicitly or implicitly apply an ad hoc adjustment factor or multiplier (e.g. increase the risk aversion applied in pricing).

Therefore, as the objective of this study is identifying accurate benchmarks for supervising these risks, the risk aversion applied in pricing by each insurer is an important point of reference of the risk aversion of each company, facing these risks, as well as the timeframe used in modelling processes.

V CHAPTER 5: CONCLUSION AND FUTURE RESEARCH

V.1 FINAL CONCLUSIONS AND RESULTS

Based on the quantitative result exposed in chapter III Transition risk, the total investment portfolio of the insurance market of Portugal at risk is -1.77% in orderly scenario, -4.97% in a disorderly scenario and a -1.97% in Too little, too late scenario. But we already saw that the investment portfolio of Portugal is mainly concentrated in sovereign bonds, representing the least affected investment in an orderly scenario, but not the least affected in a disorderly scenario, derived from possible sovereign costs and not coordinated efforts. As it was exposed in chapter II, Sustainable Development Goals represents an accurate benchmark for monitoring the advance of the main issuer of sovereign bond in the investment portfolio of Portugal during the transition to a sustainable finance. For the case of stocks, corporate bond, and other investments, the EU taxonomy will allow to monitor the transition risk exposition in these investments.

Furthermore, to develop this stress test in sustainable finance it was necessary to theoretically identify and analyse a financial benchmark. Given the coherence in the result of the analysis developed in point III.2.2.1.1, it was selected a benchmark developed by the DNB bank, to include it as a risk metric: Climate systematic risk, based on CO_2 emissions and value generation.

On the other hand, based on the statistical analysis developed in chapter IV, we can conclude that by using an 81-years timeframe, instead of 31-years, we are working with a wider variation in the distribution of the data, possibly affecting pricing decisions. Consequently, the risk aversion applied in pricing by each insurer is an important point of reference of the risk aversion of each company in front of the uncertainty of climate change, as well as the ambiguity in the selection of the timeframe used in modelling processes. Therefore, EurAIC represents a crucial scientific benchmark that will allow to monitor the increases in the frequency distribution, based on a coordinated actuarial and scientific effort.

In this study we could see that transition risk and physical risk have different characteristics, and the results of each study are not easily compared. Therefore, a qualitative assessment could complement the results exposed in this study, with the aim of overseeing the integration of these risks in the different components of the value chain of insurers. For this a survey[46] based on actuarial issues was developed and proposed in internal report of this internship.

It is important to mention that potential mitigations effects embedded in the exposure were not included, while there is still significant uncertainty regarding the technologies that will indeed dominate in enabling the transition.

V.2 FUTURE RESEARCH

Transition risk assessment, applied in this study, can be updated with the latest information available, it also could be adequate to develop this study with different delimitations in the applied methodologies, with the aim to compare different outcome. However, it is expected that during this decade multiples studies and methodologies will be developed, so it would be convenient to carried out transition risks assessment in a coordinated manner (e.g. NGFS frameworks) until the transition to a low-carbon economy and sustainable financial is achieved.

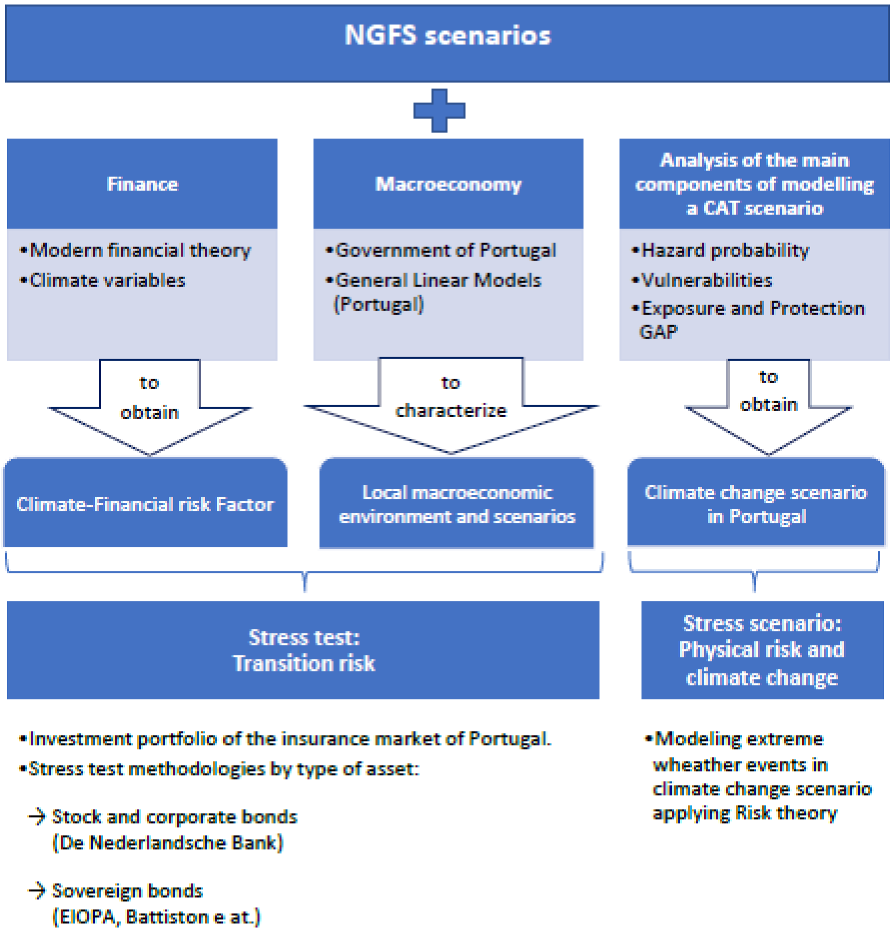
Physical risk analysis developed in this study could be complemented by the addition of a climate change scenario based on scientific studies about frequency and severity, nonetheless, it is still necessary to create coordinated scenarios in local terms, considering the specific geographical characteristics of Portugal.

Regarding Solvency II and climate change interaction, the insurance companies that commercialize insurance in Portugal have the mandate to calculate a Solvency Capital Requirement derived from the earthquake risk. After all, this physical risk analysis raises the natural question, would we expect the incorporation of another SCR derived from another catastrophic risk in Portugal in the coming years? For instance, risk of windstorm, knowing that this risk presents an increasing tendency on the national territory.

[46] Survey based on: IFoA (2019). Practical guide to climate change for general insurance practitioners.

ANNEX

1. Diagram of the characteristics of the stress test developed in this study



2. Network for Greening the Financial System

They provide public access to the data underlying the NGFS scenarios, available in the NGFS Scenario Explorer[47]. This scenario explorer is a web-based user interface for transition scenario results of multiple models. This provides intuitive visualization and display of time series data. This tool is based on 6 different Integrated Assessment Models (IAMs), 8 scenarios, 543 variables and 68 regions.

[47] NGFS (2020). NGFS Scenario Explorer [Online]. Available from: https://data.ene.iiasa.ac.at/ngfs/#/workspaces
This explorer is hosted by the International Institute for Applied Systems Analysis (IIASA)

Orderly transition

'It assumes climate policies are introduced early and become gradually more stringent. Net zero CO_2 emissions are achieved before 2070, giving a 67% chance of limiting global warming to below 2°C. Physical and transition risks are both relatively low'. 'Increase in investment is needed in green electricity (biomass, solar and wind) and storage, energy efficiency and carbon dioxide removal.' (*NGFS Climate Scenarios for central banks and supervisors, pp.6*).

Disorderly transition

'It assumes climate policies are not introduced until 2030. Since actions are taken relatively late and limited by available technologies, emissions reductions need to be sharper than in the Orderly scenario to limit warming to the same target. The result is higher transition risk'. 'The shift from brown to green takes place rapidly due to the delayed policy response and reduced availability of CO2 removal technologies.' (*NGFS Climate Scenarios for central banks and supervisors, pp.6*)

Too little, too late

This scenario is not included yet in the NGFS scenario framework, because none of the characteristics reflected in the pathways, projections and database are representative for this scenario. Therefore, in this study, this scenario will have the qualitative characteristics of the Confidence scenario presented in '*An energy transition risk stress test for the financial system of the Netherlands'*, De Nederlandsche Bank (2018, p.32). In this scenario, uncertainty regarding government policies to combat climate change causes a sudden drop in the confidence of consumers, producers and investors, translated into the same level of stress for all sectors.

Hot house world

'It assumes that only currently implemented policies are preserved. Nationally Determined Contributions are not met. Emissions grow until 2080 leading to 3°C+ of warming and severe physical risks. This includes irreversible changes like higher sea level rise'. 'The NGFS Climate Scenarios provide a range of physical risk data from climate impact models, alongside estimates of the economic impacts for each scenario.' (*NGFS Climate Scenarios for central banks and supervisors, pp.6*).

3. Macroeconomic variables*: transition to low-carbon economies, short- to long-term.*

Table 1. **Impact of climate change on key macroeconomic variables: main findings**

Variables	**Types of climate risk** *Timing of effects* *NB: The short- to medium-term impacts of extreme weather events and gradual warming need to be assessed differently from those related to transition risks, which are subject to policy uncertainty and therefore depend on different factors*		
	Physical risk: extreme weather events *Short- to medium-term*	**Physical risk: gradual warming and more volatile temperatures and precipitation patterns** *Medium- to long-term*	**Transition risk: transition to low-carbon economies** *Short- to long-term*
Output	Lower due to physical destruction (crop failures, destruction of facilities and infrastructure, disruption of supply chains and tourism).	Lower due to lower labour productivity, investment being diverted to mitigation, and arable land losses.	Capital and labour reallocation process could create frictions across sectors as a result of distortive (fiscal) transition policies and/or (fiscal) transition policy uncertainty and associated insufficient/ inefficient investment. Mitigated impact depends on the use of proceeds from (fiscal) transition policies.
Consumption	Lower due to increased uncertainty, e.g. surrounding housing wealth and future income prospects. Higher due to increased household demand to replace destroyed goods, or hoarding behaviour.	Higher volatility due to shifts in sectoral demand.	Likely lower due to increased sustainability awareness (e.g. preference for circular economy). Shift towards greener goods and/ or services can also spur sectoral shifts, but the impact on aggregate consumption is uncertain.
Investment	Lower due to increased uncertainty, volatility and direct destruction of the capital stock. May pick up following an extreme event, but the effective or useful stock of capital may well be lower. Diversion of investment away from productivity-enhancing investment and towards mitigation.	Shifts in investment towards climate adaptation technologies.	Higher as investment shifts towards climate mitigation technologies. Lower because of higher uncertainty surrounding future policies, the rise in stranded assets, and reduced productivity gains from the international division of labour.
Productivity	Lower labour and capital productivity due to (possibly permanent) capital and infrastructure destruction.	Lower labour productivity because of lower human capital accumulation (as a result of increased health issues and mortality).	Effect on productivity uncertain because technological progress could offset the under-investment that is likely to materialise because of transition policies and the rise in stranded assets.
Employment	Lower because of the destruction of physical assets and the dislocation of people from the immediate vicinity of a disaster area. Potential frictional unemployment, which can be mitigated if labour mobility is sufficient.	Reduction in labour supply in exposed industries such as construction and agriculture, where it becomes less desirable to work in higher temperatures. Increased international migration flows, might raise the labour supply in less affected regions.	Changes in sectoral composition of labour market might trigger a rise in structural unemployment.
Wages	Uneven effects across sectors and economies (agriculture, tourism and construction are most exposed in developing economies). Reallocation of the workforce can generate labour shortages in some sectors where wages could increase temporarily. Wage patterns contingent on the length of the disaster effects (e.g. flooding).	Lower wages could result from lower productivity caused by gradual warming.	Potential shift of workers from one sector to another and their training needs.

International trade	Disruption of import/export flows due to disasters could lead to lower incomes via loss of export markets or higher import costs. Supply chain interruptions can lead to supply disruptions. Tourism may suffer from destruction of infrastructure.	Disruption of trade routes due to geophysical changes (such as rising sea levels). Increases in average temperatures could diminish export values.	Taxes, regulations and restrictions might disrupt import and export routes. Changing international demand for different types of energy products may affect energy exporters and importers differently. Risks of distortion from asymmetric or unilateral climate policies. Robust and open international trade infrastructure can act as a buffer absorbing some of the negative impacts of climate change shocks.
Exchange rate	Depreciation pressure on currencies of economies affected by climate disasters, because of negative terms of trade shocks and lower labour productivity.	Depreciation pressure on currencies of economies frequently affected by climate disasters and/or losses of arable land, because of extreme temperatures.	Freely floating exchange rate may offer an absorption capacity for shocks, especially for economies perceived as being further away from a low carbon standard.
Inflation	Increased inflation volatility, especially regarding food, housing and energy prices. Heterogeneous impacts on headline inflation, with the impact being stronger and more persistent in developing countries. Impact on inflation expectations.	Relative price changes due to shifting consumer demand or preferences and changes in comparative cost advantages.	Energy prices affected most by climate-related transition policies, such as CO_2 allowances and carbon taxes. Policy uncertainty could weigh on inflation through its impact on investment, demand and inflation expectations. Inflationary pressures may be mitigated by technological changes that improve productivity or resilience, or by shifting consumer preferences towards climate-friendly products and services that should gradually enter the consumer basket when the consumer basket weights are updated.
Inflation expectations	More homogenous, sudden and frequent revisions of expectations will be induced. Potential decline in the overall dispersion of inflation expectations (due to a more synchronised response by professional forecasters). Information rigidities tend to disappear following natural disasters (on a major scale).	Longer-term impact of climate-related shocks on actual inflation, e.g. on food and energy prices, may affect inflation expectations (due to reciprocal causality between these two variables).	Formation of inflation expectations will be affected, e.g. through changes in tax measures. Actual inflation impacts of transition policies might also affect inflation expectations.

Source: NGFS (June 2020)

Interest Rate

Typically, central banks estimate the real rate of interest that is consistent with stable inflation when the economy is growing at full employment. The estimation of this "natural interest rate" (NIR) is one element which helps to define the monetary policy stance (accommodative, neutral or restrictive), given a country's position in the economic cycle.

Overall, the effect of climate change on the NIR, via various drivers and its potential impact of climate change:

Table 2. **Climate change and the natural interest rate (NIR)**

Channel	Potential impact of climate change
Growth	Ambiguous • Lower NIR as climate change might discourage labour supply, lower labour productivity, and shift age composition of population. • Higher NIR for countries attracting migration flows as climate change increases their labour supply.
Technology	Ambiguous • Lower NIR through diversion of resources away from innovation and towards mitigation and adaptation. • Higher NIR as environmental regulation may foster the search for efficiency gains and encourage innovation.
Savings behaviour	Lower NIR through increased preference for savings driven by (i) greater income inequality (the poorest part of the population is typically more exposed to the consequences of climate change), and (ii) higher uncertainty about the future.
Risk premium	Lower NIR as climate change could increase preference for holding safe assets.
Fiscal policy	Higher NIR as government debt rises because of increased mitigation and adaptation investment or higher expenditure to cover health and other costs of natural disasters.

Source: NGFS (June 2020)

4. Statistical summary of GLM 1, 2 and 3.

```
Call:
glm(formula = VAGLM_GDP$Real_GDP ~ dFF + dRS + Multifactor +
    DD_Total - 1, data = VAGLM_GDP, na.action = na.exclude)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-1.00588  -0.16003   0.08089   0.68813   1.83850

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
dFF         0.022796   0.007764   2.936  0.00657 **
dRS         0.012637   0.004448   2.841  0.00829 **
Multifactor 0.258221   0.126068   2.048  0.05002 .
DD_Total    0.627854   0.051275  12.245 9.24e-13 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.549588)

    Null deviance: 370.593  on 32  degrees of freedom
Residual deviance:  15.388  on 28  degrees of freedom
AIC: 77.384

Number of Fisher Scoring iterations: 2
```

```
Call:
glm(formula = VAGLM_GDP$Real_GDP ~ DD_Total + dRS:DD_Total +
    dFF:dRS - 1, data = VAGLM_GDP, na.action = na.exclude)

Deviance Residuals:
     Min        1Q    Median        3Q       Max
-0.89433  -0.30280   0.01846   0.50235   1.80400

Coefficients:
               Estimate Std. Error t value Pr(>|t|)
DD_Total      0.6889558  0.0288915  23.846  < 2e-16 ***
DD_Total:dRS  0.0033595  0.0009662   3.477  0.00162 **
dRS:dFF      -0.0006619  0.0001212  -5.462 7.03e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 0.4001342)

    Null deviance: 370.593  on 32  degrees of freedom
Residual deviance:  11.604  on 29  degrees of freedom
AIC: 66.351

Number of Fisher Scoring iterations: 2
```

```
Call:
glm(formula = GLM_GDP$Real_GDP ~ INV_Total + dLF + DD_Total:Multifactor -
    1, data = GLM_GDP)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.7615  -0.2167   0.6288   1.5428   3.1401

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)
INV_Total             0.24981    0.04210   5.934 1.91e-06 ***
dLF                   0.32156    0.15615   2.059 0.048540 *
DD_Total:Multifactor  0.10586    0.02626   4.031 0.000368 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 2.005416)

    Null deviance: 370.593  on 32  degrees of freedom
Residual deviance:  58.157  on 29  degrees of freedom
AIC: 117.93

Number of Fisher Scoring iterations: 2
```

5. Local macroeconomic consideration of stress levels: Portugal

Investment: 'This transformation will have to be accompanied by a significant investment, which will take place in all sectors of society, and will, according to its type, be shared between investments by households, by companies and by the State. The private sector and households will be responsible for the vast majority of these investments. Thus, the 93% of aggregate amount of investment by 2050 will be realised in any case as a result of the normal dynamics of modernisation of the economy, catalysed by ongoing policies to ensure the functioning of the energy system'. in: RNC-2050 (2019), p.72

Taxes: 'Portugal has participated in CELE (Comércio Europeu de Licenças de Emissão) since 2005 and adopted a carbon tax in 2015, in the form of an addition to the Petroleum and Energy Products Tax, subsequent to the 'Green Tax Law'. Carbon pricing policies should be fostered, particularly through effective implementation of the CELE regime[48], promoting actions that lead to reinforcement of the carbon price, encouraging widespread application of the carbon tax to sectors not covered by CELE, eliminating existing exemptions.' in: RNC-2050 (2019), p.82

Employment and GDP: 'In terms of opportunities, it is undeniable that there will be a positive effect on GDP and employment caused by investments for stimulating new sectors. This investment with high potential for creating new business models, products and services, will generate wealth and employment in all the associated value chain. In terms of challenges, there will be sectors that could potentially be affected by the climate-related risk. It is therefore necessary to identify in advance which sectors will be most affected and to start designing policies that create alternative opportunities for the affected workers and/or regions.' in: RNC-2050 (2019), p.83.

The Portuguese main investments are projected to be in the Construction (49%) and Transport (41%) sector[49]. It is expected these investments will have a positive effect over the economy and labour, as the Portuguese government projected, consequently the different sectors will incorporate a macroeconomic impact, that could be positive, neutral or negative.

Taking into account the expected local macroeconomic effects, some adjustments were incorporated to reach the most accurate representation of each scenario:

- The macroeconomic variable effected are included in each scenario, following the possible effects that are explained in our macroeconomic model.
- Orderly scenario incorporates the cost of opportunity of changing the sources of energy explained by our model, as a minimum cost of opportunity effect.

[48] EU parliament and council (2018). Comércio Europeu de Licenças de Emissão [Online]. Available from: https://apambiente.pt/_zdata/CELE/Diretiva_CELE_2018_410.pdf
[49] Resolução de Conselho de Ministros n.º 107/2019 & Roadmap for Carbon Neutrality 2050 (p.73)

- Disorderly scenario must expose the energy sector as the most affected sectors by a sudden measure taken[50]. No mitigations are expected on this sector due to policy risk materialization.
- 'Too little too late' scenario is represented by a decrease in the Investment and Domestic Demand. This impact is spread over all sectors, stablishing a minimum level of stress of the local economy.
- Government compromise, about investment in specific sectors, are considered.
- Agriculture, forestry and fishing sector adjustment. According to the RNC2050, the emissions reduction in agriculture is occurring at a slower rate than in other sectors, inherent to the characteristics of the associated biophysical systems. The current proposal of a Common Agricultural Policy (CAP) seeks more effective climate action and better protection of the environment and biodiversity by the agricultural sector.

6. Modern financial theory applicable on climate-related risk assessment

This point aims to present a review of the literature on modern financial theory, with the purpose to identify which theory could be applicable on climate-related risk assessment considering the limitation exposed on point I.1, with the purpose to define a financial benchmark to be used as the risk factor in this study.

Modern financial theory

During the last decades, one of the most influencer works about modern financial theory was developed by Markowitz in 1952, which developed a mathematical relationship between risk and returns, showing that the expected return of a portfolio is the weighted average of the expected return for each security.

This idea came from The *Theory of Investment Value*, John Burr Williams, who proposed that the value of a stock should be equal the present value of its future dividend stream. Since, the dividends are uncertain, Markowitz developed the idea of an expected value of its discounted future dividend stream. But linked with this expected value and a rational

[50] From 1981-2019 the weighted average of default for the Energy sector was 3.1% approx., even for the 2019 it was almost 4%, being the highest default rate through the different sectors. See it in the chart number two: https://www.spglobal.com/ratings/en/research/articles/200429-default-transition-and-recovery-2019-annual-global-corporate-default-and-rating-transition-study-1144486

investment behaviour exist an associated risk that should be measured for the portfolio of the investor. Variance of a weighted sum (or, equivalently, standard deviation), was an accurate measure of risk, where it involves all covariance terms.

Many other authors continued developing this idea, James Tobin was one of them who added the concept of the 'super-efficient portfolio' that incorporate the risk-free asset in combination with the risky assets (Tobin, 1958).

Nowadays, we just need databases, computer algorithms and methods of estimations, to trace out mean-variance frontiers for large universes of securities, where the expected return is maximised, and the risk is minimised. But Markowitz continued developing the theory and arrived at the natural question of, is this the right thing to do for the investor? In particular, are mean and variance proper and sufficient criteria for portfolio choice?[51]

In 1960s, Samuelson and Fama incorporated the efficient markets theory, which says that market prices fully reflect all available information. In a paper, 'Random Walk in Stock Market Prices", published in the Financial Analysis Journal, it is explained the idea that in an efficient market, at any point in time, actual prices of individual securities already reflect the effects of information based both on events that had already occurred and on events which, as of now, the market expected to take place in the future (Fama, 1965).

In 1964 W. Sharpe, suggested that Tobin's super-efficient portfolio was in fact the market portfolio, given that the market provides the best available evidence of prices, conclusion from the combination of the efficient market hypothesis and the modern portfolio theory developed by Markowitz. From these, the Capital Asset Pricing Model (CAPM) rose, which identify two types of risks, systematic risk (called beta), which all securities contain, and idiosyncratic risk, that correspond to the specific risk of an individual security, such risk is scattered by the investor when he or she invest in the feasible region. If so, diversification enables the investor to scape all but the risk resulting from swings in economy activity – this type of risk remains even in efficient combinations.

[51] Foundations of portfolio theory, Harry M. Markowitz. 1990.

Risk factors into the market

Sharpe argued that in equilibrium there will be a single linear relationship between the expected return and standard deviation of return for efficient combinations of risky assets, being a consistent relationship between the asset expected returns and the systematic risk. Therefore, we can directly represent the linear regression exposed by Sharpe since the relationship between the magnitude of this type of risk and the assets expected return.

Onward, this theory became the major analytic tool for explaining phenomena observed in capital markets for risky assets. The CAPM assumes some explicative factors analysed by Sharpe, then many studies have been developed seeking to explain different risk associated with the risk asset market.

During the following years, there had been many authors interested in multi-index models. Testing and proving that many betas best explain the historical variance-covariance or correlation matrix. Roll and Ross (1980) report that at least three indexes are needed to explain the historical variance–covariance matrix. Dhrymes, Friend, and Gultekin (1984) showed that the number of indexes that are needed is very dependent on the number of firms that are being analysed. Depending on the sample size, they found that many more than three are needed. Finally, Gibbons (1982), analysing bond and stock data, finds that six or seven indexes are needed.

Later, Chen, Roll, and Ross (1986), and Burmeister writing with others (1986, 1987, 1988), have produced a set of multi-index models based on a priori hypothesized set of macroeconomic variables.

Therefore, as we know our financial analysis cannot be based on backward-looking analysis, nonetheless, by using CAPM theory, we can define a risk index based on current climate factors and macroeconomic variables by sector.

7. Insolvency probability regression

```
Call: rq(formula = EC$`IR_%` ~ laverage + Real_GDP, tau = c(0.5, 0.75),
    data = EC[, -1])

tau: [1] 0.5

Coefficients:
            Value    Std. Error t value  Pr(>|t|)
(Intercept)  7.50123  0.71103   10.54974  0.00000
laverage    -0.71572  0.07903   -9.05683  0.00000
Real_GDP    -0.04927  0.02272   -2.16843  0.03431

Call: rq(formula = EC$`IR_%` ~ laverage + Real_GDP, tau = c(0.5, 0.75),
    data = EC[, -1])

tau: [1] 0.75

Coefficients:
            Value    Std. Error t value  Pr(>|t|)
(Intercept)  9.21296  0.92698    9.93872  0.00000
laverage    -0.89024  0.10119   -8.79783  0.00000
Real_GDP    -0.07485  0.01195   -6.26260  0.00000
```

8. Elasticity by country

The transition is carried out on a schedule that is not predictable by markets and investors, e.g., a new policy in a disorderly transition. In this case, we assume that the climate policy shock from a disordered transition is not anticipated by the investor, nevertheless it could be potentially expected.

Thus, an essential point was to identify if the countries are behind schedule in reducing CO_2 levels, assuming any posterior effort will bring stronger financial consequences.

Given that the 11 countries, with higher representativity in the sovereign investment portfolio of the insurance market of Portugal, are European, then the EU targets were used to analyse this elasticity. Specifically, the European Commission informed in official communiqué[52] the legal framework adopted by the European Council, the targets for renewables and energy efficiency:

- Greenhouse gas emissions – a cut of at least 40% below 1990 levels by 2030.
- Renewables – increasing to at least 32% share of final energy consumption[53].
- Energy efficiency[54] – increasing by at least 32.5%.

Risk elasticity based on EU targets

Therefore, the elasticity was determined by evaluating the current situation of each country in each goal. First, to determine the current CO_2 levels needed to achieve the first

[52] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the committee of the regions: A policy framework for climate and energy in the period from 2021 to 2030.
In 2018, the targets for renewables and energy efficiency were revised upwards.

[53]https://ec.europa.eu/energy/topics/renewable-energy/renewable-energy-directive/overview_en

[54] https://ec.europa.eu/energy/topics/energy-efficiency/targets-directive-and-rules/energy-efficiency-directive_en

goal; second, to determine the current levels of renewable energies in energy generation and final consumption; and third, to assess the evolution of the value added generated per unit of CO_2 emitted by each country since 2005[55].

Thus, the elasticity of the transition risk is denoted by χ, composed by three elasticities,

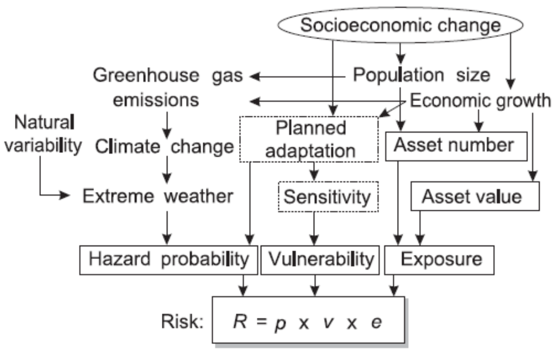
(26) $$\chi_j = \left(\chi_{target\ 1} \times \chi_{target\ 2}\right) + \chi^D_{target\ 3}$$

Where, χ_j represents the total elasticity risk given the target compliance mentioned above. Elasticity 1 and 2 represent the percentage necessary to achieve target 1 or 2, then the multiplication allowed us to identify those cases in which one of these goals has already been achieved. On the other hand, elasticity 3 was defined as a dummy variable that analyses the energy efficiency over time, assessing the evolution of the systematic risk presented in equation (5).

Finally, we obtain:

(27) $$\Delta v_j(P) = e^{-r_f(T-t_0)} e^{r_j(B)(T-t_0)} \left(e^{-\chi_i \times LGT_j \times \frac{VA_j(s)}{VA_j}} - 1\right)$$

9. Framework for modelling risk from extreme weather events



10. Detailed AAL and Sd calculations

31-years	Climatological	Hydrological	Metereological
E[N]	0.39	0.29	0.52
E[X]	269,105	49,689	15,094
E[S]	**104,170**	**14,426**	**7,790**
V[X]	580,434,156,398	72,380,498,653	3,239,879,704
V[N]	0.38	0.28	0.52
E^2[X]	72,417,501,025	2,468,970,883	227,820,082
V[S]	**252,093,837,636**	**21,703,944,501**	**1,791,740,177**

81-years	Climatological	Hydrological	Metereological
E[N]	0.21	0.17	0.21
E[X]	157,897	125,985	5,777
E[S]	**33,139**	**21,775**	**1,212**
V[X]	351,169,865,955	325,608,495,544	1,269,448,888
V[N]	0.24	0.19	0.27
E^2[X]	24,931,557,347	15,872,094,240	33,369,165
V[S]	**79,758,207,570**	**59,369,149,122**	**275,367,129**

[55] The energy efficiency is analysed under the fact that these efforts are being proposed since previous agreements; United Nations Framework Convention on Climate Change (1992), Kyoto Protocol agreement (1997), Kyoto Protocol into effect (2005) and Paris agreement (2015).

BIBLIOGRAPHY

Chapter 1

- European Insurance and Occupational Pensions Authority. Solvency II templates [Online]. Available from: https://www.eiopa.europa.eu/tools-and-data/supervisory-reporting-dpm-and-xbrl_en
- European Insurance and Occupational Pensions Authority (Sep. 2019). Opinion on sustainability within Solvency II.
- International Financial Reporting Standards (Nov. 2019). IFRS Standards and climate-related disclosures.
- Climate Action Tracker (Dec. 2019). Warming Projections Global Update.
- Network for Greening the Financial System (Abr. 2019). A call for action: Climate change a source of financial risk.
- European Commission, Joint Research Centre, JRC Scientific and Policy Reports (2014). Climate Impacts in Europe, The JRC Peseta II Project.
- Paris agreement. Further information [Online]. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement
- Network for Greening the Financial System (May 2020). Guide for Supervisors. Integrating climate-related and environmental risks into prudential supervision.

Chapter 2

- Sustainable development in the EU: Monitoring report on progress towards the SDGs in an EU context. 2020 edition.
- EU commission (May 2020). 2020 European Semester: Country-specific recommendations.
- Regulation (EU) 2020/852 of the European Parliament and of the council of 18 June 2020, on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088.
- United Nations. Sustainable Development Report [Online]. Available from: https://dashboards.sdgindex.org/

- Task Force on Climate-related Financial Disclosures (June 2017). Recommendations of the Task Force on Climate-related Financial Disclosures.
- Task Force on Climate-related Financial Disclosures (June 2019). Status report.
- EU Technical Expert Group on Sustainable Finance (TEG) (March 2020). Taxonomy: Final report of the EU TEG on Sustainable Finance.
- Network for Greening the Financial System (June 2020). Guide to climate scenario analysis for central banks and supervisors.
- Network for Greening the Financial System (2020). NGFS Scenario Explorer [Online]. Available from: https://data.ene.iiasa.ac.at/ngfs/#/workspaces This explorer is hosted by the International Institute for Applied Systems Analysis (IIASA)
- Network for Greening the Financial System (June 2020). The Macroeconomic and Financial Stability Impacts of Climate Change.
- Network for Greening the Financial System (June 2020). Climate Change and Monetary Policy.

Chapter 3

- OECD (2020). Annual country statistical profile [Online]. Available from: https://data.oecd.org/portugal.htm
- Ministry of the Environment and Energy Transition (2019). Roadmap for Carbon Neutrality 2050.
- De Nederlandsche Bank (2018). An energy transition risk stress test for the financial system of the Netherlands.
- De Nederlandsche Bank (2018). Web-appendix: Modelling the energy transition risk stress test.
- De Nederlandsche Bank (2017) A top-down stress testing framework, DNB.
- Battiston, S. & Monasterolo, I. (Mach 11, 2020). A climate risk assessment of sovereign bonds.
- Recommendations of the Task Force on Climate-related Financial Disclosures, Financial Stability Board, 2017.
- Task Force on Climate-related Financial Disclosures: Status Report. Financial Stability Board, 2019.

- Default, transition, and recovery: 2019 annual global corporate default and rating transition study (2020). https://www.spglobal.com/ratings/en/research/articles/200429-default-transition-and-recovery-2019-annual-global-corporate-default-and-rating-transition-study-11444862
- Elton, E., Gruber, M., Brown, S. & Goetzmann W. (2013). Modern portfolio theory and investment analysis [Ninth edition].

Chapter 4

- European Insurance and Occupational Pensions Authority (Dec. 2019). Methodological principles of insurance stress testing.
- European Commission (Aug. 2017). Insurance of weather and climate-related disaster risk: Inventory and analysis of mechanisms to support damages prevention in the EU.
- Institute and Faculty of Actuaries (Aug. 2019). Practical guide to climate change for general insurance practitioners.
- European Insurance and Occupational Pensions Authority (Sep. 2019). EIOPA Staff discussion paper: Protection gap for natural catastrophes.
- European Insurance and Occupational Pensions Authority (Dec. 2019). Meteorological principles of insurance stress testing.
- Gumbel, E.J. (1958). Statistics of Extremes. Columbia University Press, New York.
- Bob Buhr, at. (2018). Climate change and the cost of capital in developing countries: Assessing the impact of climate risk on sovereign borrowing costs. College Business School and SOAS-University of London.
- European Insurance and Occupational Pensions Authority (Sept. 2019). Opinion on sustainability within Solvency II.
- Simon Dietz and Falk Niehörster. Centre for Climate Change Economics and Policy, and Grantham Research Institute on Climate Change and the Environment (August 2020). Pricing ambiguity in catastrophe risk insurance.
- The Review Worldwide Reinsurance (2008). A guide to catastrophe modelling.